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AUTHOR	Smode, Alfred F.
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ABSTRACT

Guidelines are presented for achieving human factors inputs to the design of synthetic training systems. A method is developed for design and organization of training concepts and data supportive to the human factors specialist in deriving the functional specifications for the design of any complex training device. Three major sections are provided. The first of these presents an organized method for achieving human factors inputs to training system design. Another section presents concepts and data applicable to the design of training devices--visual simulation, platform simulation, vehicle control requirements, information processing requirements, measurement system design, adaptive training strategies, and deliberate departure from realism in design. Design support for each of these factors is articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Research issues of high priority for human factors design are recommended. The third section contains a demonstration of the human factors design process for a complex training system. (Author/JY)

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Technical Report: NAVTRADEVCEN 69-C-0298-1

HUMAN FACTORS INPUTS TO THE TRAINING DEVICE DESIGN PROCESS

Alfred F. Smode

Dunlap and Associates, Inc.
Darien, Connecticut 06820

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ABSTRACT

This report presents guidelines for achieving human factors inputs to the design of synthetic training systems. It provides a method for design and organizes training concepts and data supportive to the human factors specialist in deriving the functional specifications for the design of any complex training device.

Three major sections are provided. The first of these presents an organized method for achieving human factors inputs to training system design.

Another section presents concepts and data applicable to the design of training devices. Seven content chapters are subsumed under this section. These are:

- Visual simulation
- Platform motion simulation
- Vehicle control requirements
- Information processing requirements
- Measurement system design
- Adaptive training strategies
- Deliberate departures from realism in design.

For each chapter, concepts and data which provide human factors design support are articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Research issues of high priority for human factors design are recommended.

The final section provides a demonstration of the human factors design process for a complex training system. A reconstruction of the human factors specifications for Device 14A2, ASROC/ASW Early Attack Weapon System Trainer, is presented. The required human factors inputs are systematically explored based on the method mentioned above. Viewing an "on-line" training device in retrospect provides the opportunity to examine the credibility of the method proposed in this report, particularly in relation to the design achieved. It also enables the reconstruction of the key human factors decision points including an examination of the possible design alternatives in terms of what effects these could have had on the instructional capability of the device.

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FOREWORD

Over the past quarter century, the literature on training devices has grown to voluminous proportions. A glance at the bibliography in this report will confirm this. It was the purpose of this project to select, out of this welter of information, what was sound, what was based on principles of human learning, what was supported by hard data, and to put this together within two covers to provide a source book and reference guide to the design and construction of training devices. This volume is designed to serve the needs of all those concerned with the development of training devices, Project Officers and Engineers and Human Factors Personnel who round out the device team.

Dr. Alfred F. Smode of Dunlap and Associates gathered the information, organized it in its present form, and wrote the report. Dr. Knox E. Miller of the NAVTRADEVCEN devised the method for developing visual simulation specifications and described it in Section 3.1.3. Dr. Hugh M. Bowen of Dunlap and Associates wrote the rest of the Chapter on Visual Simulation, and Dr. Herbert Smithline of Dunlap and Associates contributed the Chapter on Vehicle Control Requirements.

Vincent J. Sharkey
VINCENT J. SHARKEY
Psychologist

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SECTION I

INTRODUCTION

1. INTRODUCTION

1.1 PURPOSE. This report presents guidelines for human factors inputs to the design of synthetic training systems. It provides a method for design[1] and organizes training concepts and data supportive to the human factors specialist in achieving the functional specifications for the design of any complex synthetic training system wherein the training device (simulator) is the focal point of the instructional system, i.e., the primary means for training.

The method is constructed to facilitate the rapid development of a human factors design pathway by making explicit the data application points and the alternatives available for achieving the design concept for any training system under consideration. In essence, the method is devoted to procedures and techniques that may be used to advantage in training device design; guideline information (concepts and data) is also provided to assist the human factors specialist in identifying those design strategies and options which will enhance the transfer of training achieved via simulation.

1.2 PERSPECTIVE. The emphasis in this presentation is on human factors inputs as elements in the training device design process and is concerned with the design and utilization of the simulator as a training tool. It centers on the issues of human factors responsibility in device design, and on the information and data needed to fulfill this responsibility, specifically, what information is immediately available for design use, how well the findings of research translate to the specific problems of design, what data gaps hamper efficient design decisions; and the methods (procedures, techniques) available to enable the rapid development of a design pathway for specifying a relevant and effective training system.

The human factors goal is to provide an instructional capability consistent with the defined purpose of the training device. The requirement is easily described: provide a design to maximize transfer of training (correlation of performances in the simulator with the performances required in the real world counterpart). This involves the capability for structuring training (hardware and software) so that critical system/mission events can be installed and controlled to occur in prescribed ways at prescribed times. Flexibility in task representation and control with the capability to monitor, evaluate and score performance is the basis for the development of training strategies. The design objective is to specify the characteristics of the pertinent operational environment to simulate for training, and the human factors effort concentrates on selecting the design alternative(s) which will define the manner in which the synthetic environment for training will be provided and how learning will be shaped (structured and controlled). This embraces two distinct but interrelated operations: 1) trainee station design, which considers most prominently the issues involved in achieving fidelity of simulation, that is, specifying the characteristics of hardware (displays/controls) and the functions with which the trainee must interact in the device and their fidelity of representation; and 2) the management of training, which concerns the structuring, controlling, and monitoring of training at the instructor station. Achievement of these design requirements is the subject of this document.

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[1] This method is applicable generally to any training device design effort; it is also compatible with the Naval Training Device Center's currently used Military Characteristics (MC) Instruction (NAVTRADEVCEN INSTRUCTION 3910.4, July 1969). The purpose of an MC Document is to identify a training problem, and, when required, to define and describe the functional training characteristics of a device required to provide the needed training capability.

Material is presented to provide design guidance pertinent to most classes of training devices with the emphasis on complex weapons system trainers. By concentrating on the more difficult classes of training devices, it is our belief that the requirements for more simple training devices and part-task trainers can be handled equally well via the content of this document (i.e., design options for more difficult or complex problems serve as models for solving less stringent problems). Thus, the guidelines are applicable to the major classes of training devices currently in the Navy inventory.

The document is directed primarily towards individuals charged with the responsibility for human factors inputs during the conception and development of the design of training devices. It is our assumption that in the design of a specific training device this document will be of maximum value to the human factors specialist who, 1) is already skillful in the design process, and 2) is or will become intimately familiar with the nature of, and the characteristics of the specific system under consideration. This is in keeping with our intent to provide guidance and support (i.e., guidebook, not handbook, format) to the human factors effort in any device design.

1.3 PROBLEMS IN GUIDELINES DEVELOPMENT. As a prelude to the presentation of the material in this guide, we recognize the substantial hazards associated with organizing guidelines for human factors inputs to training device design. Any attempt to formalize the strategies and the available design options to optimize the instructional value of training devices and to provide guidelines of general utility which will satisfy the requirement of "something for any situation" is frought with difficulties, both in content and format. One class of difficulty is the lack of standard procedures in device development. Each procurement is handled according to its own merits and constraints. Foremost among these is the type of operational requirement/system to which the device pertains, the purpose to be achieved by the device, and the design information already available (e.g., an operational system vs. a system in some stage of development). Another compelling difficulty is that today no method prevails which demonstrates convincingly a means for exploiting information that will yield consistently effective solutions to training problems.

Thus, our development of the issues and problems which influence the selection of human factors design options has been constrained by the following features.

a. The methods for achieving human factors design solutions are inexact. We have attempted to assemble the most coherent approaches to design. These unfortunately are of differential usefulness, therefore, the recommendations are of differential utility.

b. The information base of concepts and data pertinent to design is weak. We have attempted to select the research results most applicable to simulator design (for example, threshold data on motion perception rather than data on tolerances to excessive G). Also, researches yielding generalizable data were sought. Excluded were studies requiring major extrapolations to bring the findings in line with design utility.

c. Considerable gaps in design data and information of marginal value exist. We have attempted to describe the weaknesses in the data base and have recommended research issues of foreseeable priority based on the status of research in defined areas.

1.4 THE ISSUE OF FIDELITY. Ingenuity is required in assembling a synthetic representation of some portion of the real world in a way that will train a man to perform better in that real world. The view of the simulator as a training tool places a premium on transfer of training (via the selection of design alternatives which consider both cost and training technology). Historically, simulation design has been preoccupied with the problems of achieving maximum fidelity of simulation. This quest for physical correspondence to the operational environment (i.e., engineering fidelity in representation) has often placed the development of a relevant training program and instructional strategies in a secondary design role. In fact, some of the design practices in the attempts to achieve this "real world" physical equivalence have at times increased costs with no corresponding increase in training value and in some instances have actually interfered with realizing the full training potential of simulators.

A question of importance in this report concerns the role of the human factors specialist in defining the requirements for fidelity of simulation in a training system. Beginning with the assumption that costs and the engineering state-of-the-art are the overriding constraints in providing the environment in which learning can be made to occur, how is fidelity most effectively correlated with instructional strategy? The human factors specialist must consider fidelity of simulation in terms of structure and control of training (based on the training requirements analysis as described in Section II of this report). In structuring the environment for learning, the fidelity of representation must fulfill the training and utilization expectancies for the device. Maximum engineering fidelity is specified to the extent that it facilitates the development of desired performances, however, well designed simulators also deviate intentionally from operational realism in order to promote learning. Thus, several approaches to fidelity must be considered interactively in design and played against the purpose and objectives of the contemplated training (see Section 2.7.2):

a. The Extent of Simulation Required--this refers to the what (amount) of simulation desired (i.e., the inclusion or exclusion of a simulation element). The issue concerns what should be simulated (attainable in state-of-the-art engineering terms) to provide an environment necessary to achieve the defined purpose and objectives of training. An example of such a design alternative is the option to provide knuckles and wakes in sonar simulation as sources of false targets.

b. The Degree of Fidelity Required--this refers to the degree of physical correspondence to the operational environment and concerns the fidelity levels required to achieve effective training. Involved is a continuum of engineering fidelity ranging from a selection of alternatives when the state-of-the-art is adequate to achieve any of a number of definable options, to a reduction in fidelity tolerances when the engineering state-of-the-art is less than adequate. The most efficient selection of degree of fidelity should be based on man's perceptual requirements, i.e., perceptual equivalence to the operational environment. All other things equal, reduced engineering fidelity with attendant cost reductions is desired when it can be demonstrated that training effectiveness is not compromised.

c. Deliberate Departure From Realism--this refers to intentional gross deviations in configuration/operation from that found in the operational system or environment being simulated. Representative techniques include the use of signal enhancement, information feedback about performance, and cues and prompts in equipment design.

The human factors specialist is less concerned with the method of simulation than with what is represented at the display and control interfaces. His interest in fidelity of simulation is in terms of the trainee's interaction with the instructional system and in the training process for maximizing transfer of training. He must know the operational environment in order to make judgments about needed simulation elements to provide the training capability; knowledge of the operational environment is necessary to define alternative ways of representing the environment in which training will be accomplished. He must also know the trainee's capabilities, vis-a-vis, the design requirements (for example, the decision on the number of targets to present is most meaningful in terms of how much information the trainee can handle and process).

1.4.1 Computer Advances. With increasingly abundant computer capacity, it appears quite useful not to "skimp" on high fidelity as an approach to design (although this runs counter to a minimum initial cost design philosophy). At issue is the provision of maximum flexibility in trainer usage. For example, the inclusion of more than the minimum in simulation elements may heighten considerably the training capability and flexibility of the simulator (heightened engineering fidelity and complete representation may be extremely desirable in a number of subsystem areas). Careful consideration of increased capability and flexibility in design, with the attendant costs, may minimize later requirements for expensive modifications to a training device once it is on-line and training experience (hindsight) is obtained with it.

The advances in computer capabilities have solved some of the design problems of an earlier time (e.g., target characteristics, maneuverability, number of targets displayed, etc.) and excess computer capacity can be used to minimize existing design problems. Hunt (1967) suggests that the substitution of an increasing computer capacity for expensive engineering ingenuity is inevitable. He suggests, for example, that the generation of an acceptable mathematical model for aerodynamic and engine performance can be considerably simplified by usage of large numbers of multi-variable functions (requiring considerable computer capacity). Lavish computational power (e.g., extremely rapid computation) can be utilized to resolve some prominent and long standing problems, in visual and in motion simulation, in realistic simulation of control forces throughout all operating conditions, in radar land mass simulation (i.e., digital storage of the massive data file), and in realistic generation of ECM expendables (e.g., chaff bundles).

A basic issue is to determine the most desirable fidelity levels for the simulation parameters when the engineering state-of-the-art is adequate, and the fidelity levels that are achievable when reduction in tolerances is required because of inadequacies in the engineering state-of-the-art. These deliberations must consider the following in relation to the real world: 1) idealized representation, for example, the best equations obtainable; 2) realistic representation, for example, simplified equations involving backing-off from fidelity for the purpose of economy, and 3) implementation of the selected fidelity option, i.e., an additional attenuation in fidelity resulting from mechanization.

1.5 ORGANIZATION OF THE REPORT. In order to arrange and discuss the wide content range selected for this guide, three major sections are presented, in addition to the Introductory Section. Section II provides a method for achieving human factors inputs to training system design. Section III presents concepts and data applicable to the design of training systems. Section IV presents a demonstration of human factors recommendations in the design of a synthetic training system. This is a reconstruction of the human factors design process in achieving device specifications (for device 14A2, ASROC/ASW Early Attack Weapon System Trainer), and is based on the method depicted in Section II.

Seven content chapters are subsumed under Section III. These are:

- Visual simulation
- Platform motion simulation
- Vehicle control requirements
- Information processing requirements
- Measurement system design
- Adaptive training strategies
- Deliberate departures from realism in design

For each chapter, concepts and data which support the human factors effort in design are articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Finally, research issues that are of priority for human factors design of training devices are recommended. The philosophy underlying the research recommendations is that each issue outlined is either 1) specific to an obvious need in device design, or 2) intended to increase the understanding of human behavior which will prove fruitful in solving training problems not easily examined.

SECTION II

METHOD FOR ACHIEVING HUMAN FACTORS INPUTS TO TRAINING SYSTEM DESIGN

2. INTRODUCTION

The idealized training system development process is made up of a number of phases which describe a chronological interrelated series of steps, each involving specific human factors considerations. The goal is straightforward: to build a synthetic system that provides training in the most efficient manner relative to the fleet's needs. Unfortunately, the means for achieving this goal are not straightforward. There are gaps in training technology relative to the design of synthetic devices; there are also considerations of tradeoffs between costs and training effectiveness that yield functional design based on sources other than the job requirements.

Within these constraints, a number of human factors techniques have evolved that have been applied to the design of the various classes of complex synthetic training systems on-line today. Overall, a style has emerged which utilizes a systems approach to the design of training systems. Broadly, this approach involves a sequence of steps in the training device design process beginning with the initial determination of the requirements for training, proceding through hardware and software design (in terms of fidelity of simulation requirements in the trainee station(s) and in the instructor station design), and ideally, ending with the development of utilization procedures to insure effective training within the capabilities of device design.

Unfortunately, this basic methodology for human factors design of training systems is sketchy, incomplete, or inexact and has not met the expectations of the people responsible for the development and design of devices, or for the development of utilization procedures once the device is delivered and on-line. The best of the methods, those that have proved most effective in achieving good design properties for training, are cumbersome and time consuming; quite often the outputs of the human factors effort are too late to substantially influence certain training features in device design.

The methods available today are not complete so far as satisfying all human factors requirements in the training device design process. At best, a given method may emphasize certain important aspects of the human factors design process but be unable to effectively account for other equally important aspects. The methods available also demand considerable skill from the training analyst since the level of analysis and the kinds of information required for a specific training system are only generally outlined; explicit procedures are not available for translating task description data into hardware configuration requirements.

A method is supplied here that attempts to minimize a number of the current insufficiencies in the design process. It organizes much of the existing useful techniques and data to provide the human factors specialist support in the development of the training requirements information to the level of detail needed, consistent with the development of the functional specifications for the training system. It employs a systems approach[1] to training device design and delineates a series of chronological phases leading to design specifications for optimizing training. This method is based on the available technology of training and assembles workable existing techniques and newer concepts into a unified human factors method for achieving training system design specifications.

The method is not inviolate. Some stages of the analyses have less clearly defined procedures than other stages because of weaknesses in the current state-of-the-art in training technology. These are identified. The method is also cumbersome in parts and requires a qualified training analyst to apply the procedures. The method utilizes the available sources of information such as system documentation, doctrinal publications, interactions with experts in the operational world and direct observation.

While the method is not simple, it nevertheless provides the necessary guidance to the human factors specialist to do his job in the most efficient manner.[2] What is set up is a pathway for rapidly coming to grips with the essential design issues pertinent to most classes of major training systems. The emphasis on class is deliberate since there is such variation among training devices that any method cannot be common to all. There are, however, commonalities between and within classes of training systems (e.g., operational flight trainers, tactical team trainers, individualized general trainers, etc.) and these will be highlighted. During the course of this development, many and diverse examples will be shown that will enable the reader to generalize to a specific system under development. In addition, a demonstration of the method applied to a current on-line training device is supplied in Section IV of this report which presents a reconstruction of the human factors design inputs for a complex tactical team trainer.

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[1] The behaviors which must be exhibited on the job is the goal of the training system. To achieve this, an integrated series of learning experiences must be provided, employing an organized hardware/software configuration to produce the behaviors required. Measurement is provided to assure that training design is compatible with job requirements. The process begins with defining the purposes and objectives of training; these provide a basis for deriving training content, methods, measures, and training hardware. The data are also useful in the development of utilization procedures for the trainer.

[2] The method yields its best results when an interdisciplinary mix of human factors, engineering, and operational requirements specialists are involved in the analyses.

The major phases of activity which will enable a complete and adequate human factors contribution to the functional specifications for a training device are outlined below. A pathway is set up for rapidly coming to grips with the essential issues in functional design pertinent to any class of proposed training device. The varieties of issues are put into perspective within a chronology of events represented in the following phases.

a. Definition of the purpose of the training system.

b. Analysis of the operational system.

c. Analysis of tasks involving the trainee(s).

  - task structure
  - training objectives
  - identification of simulation elements relative to own-vehicle characteristics, target characteristics, and the media.

d. Gross device hardware definition.

e. Definition of the characteristics of the operational environment to simulate for training.

f. Representing the operational environment in the trainee compartment(s).

g. Provisions for the management of training at the instructor station (design for the structure and control of training).

It is emphasized that the procedures for obtaining, describing, organizing and correlating information for device design are iterative, beginning with gross decisions on device requirements and culminating in specifications of the functional characteristics for the device to provide the needed training capability. The series of activities undertaken begins with the initial development of ideas on what the training device is to do and how it should be constituted. From this beginning, a continual refinement and explication of the ideas is accomplished.

The outputs resulting from the above sequence of events are detailed next in a series of five sequential and iterative phases.

2.1 PHASE I: DEFINITION OF THE PURPOSE OF THE TRAINING DEVICE. In determining the need for a synthetic training system to meet fleet requirements, an initial effort is centered on defining clearly the purpose of training. Articulate statements of training needs provide an indication of the magnitude of the training required and of the fidelity level of the device hardware and also provide a basis for what to simulate. Members of the design team must interact substantially with personnel of the using facility responsible for the training to define the purpose and mission of the training.

The requirement is this: define the design pathway and achieve initial (gross) decisions on the magnitude of training required and on the fidelity level desired in the device hardware, and also provide a basis for what to simulate. The scope of the training is outlined and that "piece" of the operational universe to be represented is documented. In achieving this, it is desirable to view the operational equipment relevant to the training device; if the system is not yet operational, then the available system documentation must be reviewed.

2.1.1 Defining the Design Pathway. Initial definition of the design pathway is accomplished by means of decisions made within the following gross categories.

2.1.1.1 Characteristics of the Environment for Training and the Trainee Involvement.

a. Type of training device (fleet requirements)

- Individual, team, or group/force training device.

  An initial effort is to specify the fleet requirements for a training system (shorebased or vehicle based) and the personnel involvement.

  Individual Training--emphasis is placed on need, type of training and aspects of the operational world in which training is accomplished, for example, an OFT requirement specifying training of student aviators and the maintenance of proficiency of rated aviators in instrument flight procedures in UH-1 rotary wing aircraft; or an OFT specifying aviator flight training only for a dual place single turbojet engine TA-4F aircraft.

  Team or Group/Force Training--emphasis is placed on type of training, for example, team coordination procedures, tactical decision-making, extent of coverage of the real-world events. These options set the stage for decisions on how much of the operational world to represent.

- Specific system vs. universal/generalized training system.

The key decision is the extent of the use of abstraction vs. a high degree of realism in trainer design, for example, the decision to represent realistically the compartments and equipments for device 14A2, ASROC/ASW Early Attack Weapon System Trainer, or the decision for greater abstraction (e.g., low-level sensor fidelity) in representing stations in device 14A6, Coordinated ASW Tactics Trainer.

Similar decisions are made concerning the need for general/universal devices for individual training.

- Part vs. whole system training.

  The decision concerns what portion(s) of the equivalent real-world are to be installed for training.

b. Training areas to represent in the device (trainee station(s) design philosophy)

- The decision concerns the selection of a single area (e.g., single aircraft cockpit) vs. multiple but interdependent areas (e.g., ASW tactical team training) vs. multiple but independent areas (e.g., multiple independent booths for aerial navigation training).
- At issue is the definition of the configuration and the operational stations to represent. This involves also the initial definition of the trainee functions to be performed at each station.

c. Definition of system components

- This concerns the decision to provide specific system suites/equipments vs. generalized/nonspecific equipments. The decision is amplified by a discussion of the rationale for the alternative selected.

d. Levels of training

- Design for initial, advanced, transition, or maintenance of proficiency training is determined.

e. Training emphasis

- For single trainee situations--define the range of the job training to be accomplished in the device.

- For multi-man situations (multiple trainee stations) the design alternatives are based on: a selective training emphasis (focusing training on key positions in the team context while other positions are only supportive), vs. an equal training emphasis (all trainees on the team receive similar training emphasis)

- Definition of the background and preparation of the trainee population is accomplished, describing minimally:

  - Who the trainees will be

  - Entry-level capabilities (extent of previous experience or billet qualifications)

  - Training exposure (one time vs. short sequence vs. recurring/refresher training) and length of the training sessions anticipated

f. Implications for fidelity of simulation (extent of simulation for trainee station(s)

- This ranges from high fidelity in simulation through deliberate departures from realism to enhance training value. The requirement is to identify the simulation requirements in fidelity levels based on the nature of the training desired.

- The initial design alternatives are based on the implications of the performances required in the device, i.e., accounting for:

  - Tactical decision making vs. procedures following behavior

  - Manual control requirements

  - Displays

  - Communications

- The design decision considers the implications of classes of behavior to be trained on fidelity requirements. High fidelity requirements usually pertain to controls, displays, compartment equipments, communications, etc., involved in procedural and manual control performances; lower fidelity and greater reliance on instructor mediation is usually pertinent to decision making and tactical problem solving performances. Thus, initial decisions on fidelity requirements are made here in terms of the nature of, or emphasis on, the classes of behavior involved in training; the design issue deals with the extent of simulation (e.g., how much and how well the representation).

- Possibilities for stylized or innovative techniques for hardware/software are identified (this may include deliberate departures from the realism associated with the operational system being simulated).

- The state-of-the-art inadequacies for achieving the tolerances demanded for simulation are identified.

g. Device dynamics (computer programing requirements)

Gross definition of the characteristics of the training environment is made concerning: own vehicle and support vehicles; target(s) characteristics; and media characteristics. (This initial definition is later expanded in Phase 5 where the simulation elements subsumed under each of these three major simulation categories are specified together with the number of, and desired envelopes/ranges/values for each.)

2.1.1.2 Provisions for the Management of Training at the Instructor Station.

a. Number of instructors and operators.

b. Instructor to student ratios during a training exercise.

c. Training device mode(s) of operation.

. The decision concerns the use of manually controlled exercise sequencing vs. automated (preprogramed scenarios) exercise sequencing, and the various modes required for instructor monitoring and control of training.

- Feasibility of employing automated adaptive training modes in exercise sequencing is examined.

d. Pre-mission requirements

- Trainee briefing requirements are described.
- The means for selection/modification/construction of new mission scenarios, off-line (if automated) are described.

e. Approach to monitor, control and evaluation of training (enroute)

- Flexibility requirements are identified for the display of trainee performance information and control of the exercise (manual or automated scenarios).
- The need for instructional assists via hardware/software is examined.

f. Performance monitoring/assessment

- Measurement system--the decision concerns the need for a measurement capability in the device, and whether the measurement system will be automated or non-automated.
- Requirements are set for the display of trainee performance information (error indications).
- Decision on hard copy records of performance (for critique purposes and for school record-keeping purposes) are made as to form and content.

g. Post-mission requirements

- Critique-hard copy printout (quantitative data in form and content) requirements are set.

- The requirement for projection display equipment(s) for mission/exercise reconstruction in critique are specified.

h. Configuration of instructor station

- Basic console requirements are outlined.
- Decisions on the use of repeater displays vs. non-repeaters (e.g., CRTs) are made.
- Any special layout considerations/design features are identified.

2.1.2 Output. An initial description of the device is prepared, defining what the training device will be. The articulation of the purpose of the proposed training device provides an initial concept of the device and a synopsis of the overall training system. This "scoping and roughing out" of the system among design personnel and using agency personnel provides the focus for the subsequent iterations leading to the decisions on the functional characteristics that define the desired device. The same issues that are identified in this initial analysis are further defined and explicated in the subsequent analyses.

2.1.3 Summary, Definition of Purpose of Training. The need for the careful and precise delineation of the purpose of the training device cannot be overemphasized. The final decisions on what must be simulated and the selection of design from among alternatives continually tie-in with the definitions of the purpose of the training device. Total design is most meaningful when specified in light of what the training is supposed to accomplish.

To assure the optimum output in this phase, it is mandatory that all individuals involved in the design have a common understanding of the training implications for the device in question. Using a simulator simply as a substitute for operational practice is contrary to the philosophy underlying training in synthetic environments. The purpose of such training is to shape relevant behaviors in order to achieve transfer of training to the operational situation. The shaping of behavior is accomplished most effectively when the training device is viewed as an instructional system.

Simulation, by definition, provides precise control of the task situations and enables deliberate omissions of aspects of the real environment that are not critical to performance, or conducive to learning or which do not yield sufficient training advantage for costs involved. It is thus important that training agencies who use synthetic training systems be encouraged to incorporate relevant training concepts in the specification of device requirements. These concepts, discussed in this document, subsume the following:

- Achieving fidelity of simulation with less than one-to-one engineering replication.

- Deliberate departures from realism (thinking about training in non-operational environment terms and in abstract terms as well as in terms of hardware duplication).

- Consideration of design in terms of device utilization, with an emphasis on the structure and control of training; on monitoring, evaluation and scoring of performance; and on the development of training strategies.

- Measurement requirements (display and recording) for critique, evaluation and quality control of training.

2.2 PHASE 2: ORGANIZING INFORMATION ON THE OPERATIONAL SYSTEM. The statements of training needs developed in Phase 1 provide the essential outline for the training device and for the portions of the operational system on which information will be assembled. This establishes the basis for the types of training required, the magnitude of the training effort, and gross concepts about the fidelity of simulation required.

A detailed familiarization with the operational system is now begun, and information is assembled which is sufficient and necessary for defining task structure. What is required is an understanding of system objectives; system structure, flow and equipment nomenclature; and system capabilities. The information sources consulted include the following:

- Naval doctrinal publications.
- Relevant technical publications; system documentation.
- Discussions with operational system experts.
- Observation of the operational system or portions thereof.

The system familiarization should center on an adequate description of the operational system pertinent to the projected training system and on an understanding of the man-machine interactions. The description is usually sufficient when the missions performed by the system are laid out, together with the functions performed by personnel who will be involved in the training system under consideration. The understanding of man-machine interactions usually involves a description of the stations (number of operators), the operator duties, and a depiction of the sequence of operations in the system. (A number of formats are available for representing the interactions of men and equipment in the system operating sequence. These are described subsequently.)

A checklist of classes of information to organize will facilitate this inquiry. The checklist provides information on the description of the system, system organization, equipment and flow, and man-machine interactions. The kinds of information needed are shown below in representative lists of questions to be resolved (see Chenzoff and Folley, 1965).

2.2.1 System Description.

- Is this a new system or an improvement on an existing system?
- What are the missions of the system; interactions with other systems?
- What specific functions does it perform?
- What tactical concepts (if pertinent) underlie the system?
- Have performance standards been established?
- What are the functional components of the system pertinent to the anticipated training system?
- What are the relevant subsystems and their interrelationships within and with other units?
- What are the inputs to the system--classes, typical rates and maximum rates?
- What operations does the system perform on the inputs?
- What are the required outputs, where do they go and in what forms?
- What are normal and minimum acceptable levels of system output, what is the maximum system capability for outputs?
- Where are the points where the quality of system outputs can be evaluated?

An example of system descriptive information for ASW destroyer operations is shown in Section IV, paragraph 4.2.1.

2.2.2 Man-Machine Interactions.

- What are the human operator(s) roles in the system?
- What and how many personnel are involved in their specific duties?

- What is the sequence of activities during a mission?
- What are the team requirements?
- What sensory inputs are received by operators, how displayed?
- What controls are operated, what are the outputs?
- What personnel qualifications are pertinent?
- Are there performance standards (e.g., speed, accuracy) for portions of system operation?
- What situational or environmental stresses, and safety precautions are personnel required to perform under?
- What aspects of the system will cause special difficulties for training?

The outputs of this effort include:

- A description of how the system is operated and employed with emphasis on those portions of the system pertinent to the planned training.
- Human operator roles in the system and the functions performed by each individual or team.
- Layout of the system by functional blocks, and analyses of the event sequences (actions, decisions, communications) in system operations.

This systems familiarization phase should be accomplished quickly as a prelude to the more detailed analysis of task structure. Several approaches (outlined in 2.2.3.3) are employed interactively to obtain and organize the desired information for describing the system.

2.2.3 System Documentation. Use is made of available documentation on the system under study. These sources provide an overall description of the system components, flow, operating modes, equipment complexes, functions performed by people, and so forth.

2.2.3.1 Discussions with System Experts. The most productive source of systems descriptive information is obtained from operating personnel who are subject-matter experts in the system, and every effort should be made to meet with these people as soon as possible and for the length of time required for system familiarization. In conjunction with this, every opportunity should be taken to observe the system first-hand and receive "walk-throughs" of the basic operations from operating personnel.

2.2.3.2 System Layout. Most often, operator-oriented documentation such as personnel functions and duties, time and event sequence charts of system activities, information flow charts, etc., are not available. Thus, the human factors specialist uses graphic analysis techniques for the needed understanding of system functioning. These event-linked diagrams present the continuity in system flow (actions, decisions, communications) and the relationships between men and equipment. The operational Sequence Diagram (OSD) is representative of this type of technique. Ideally, the development of this graphic analysis should be accomplished in conjunction with personnel who are expert in the system operations in order to maximize completeness and accuracy, and to shorten the time to accomplish.

Thus, as minimums, the following classes of information are organized:

- Information on the missions performed by the system. This is prepared in a tabular descriptive format.

- Functions performed by individuals and by subteams (as pertinent) in the system. This is prepared in a tabular descriptive format.

- Information on duties performed by each relevant operator and by duty stations (as pertinent) for the system. This is prepared in a tabular descriptive format.

- Identification of system suites and equipment components (as pertinent). In the case of universal/generalized trainers, specific equipment requirements are identified where replicas of operational equipments are needed, and the range of mission functions and events to be simulated are identified where non-specificity in equipments are called for.

- Sequence of system operation and functional layout of the system. Various graphic formats are available for gaining a gross understanding of the interactions of men and equipment.

2.2.3.3 Graphic Analysis Formats. Graphic analyses are employed to logically reduce a complex system or operation to a clearly interrelated set of functions, tasks and activities, e.g., a simplified presentation via diagrams of a complex series of relationships.

A number of variations in technique are available. For single operator systems, Information, Decision, Action (IDA) charts are useful. The format for an IDA diagram and typical symbols used in analyzing man-machine operations is shown in Figure 1. For multi-man operations, a relatively simple multiple-activity process chart may be used. Figure 2 provides an example. In practice, the most prevalent format for describing system functions and man-machine interactions is the Operational Sequence Diagram (OSD). It is structured around defined pieces of hardware, software, and operators, and is used to identify their interrelationships as the system is exercised against a scenario. Unfortunately, no single graphic format (classes of information and symbolic logic) has been standardized. In its simplest form the OSD is used to establish a sequence of operations required between subsystem interfaces at various levels of operation. In some instances, sequence diagrams are similar to block diagrams of a system, with each block in the series describing gross aspects of system operations. Sequence diagrams can be laid out in various ways. They may be spatially oriented as well as placed along a time line, or they may be used simply as an ideographic convenience. The constant purpose, however, is to organize system information in a way to depict the significant events and activities in operating the man-machine system being analyzed. Generally, a columnar format with a vertically descending time line is most preferred. Within this, the OSD is developed as a working document according to the requirements of the particular job objectives.

An example of the original development by Dunlap and Associates, Inc., (Brooks, 1960) is shown in Figure 3. Four symbols are used to denote operator action, and decision and information transmitted or received. Double-lined symbols indicate automation of the event. Usually, numbers inside symbols are used for reference to a key. This requirement for cross-referencing may become cumbersome in lengthy operational sequences. Thus, a variation is seen occasionally whereby the information is written within the symbol thereby eliminating the need for cross-referencing. Another example is shown in Figure 4 based on the symbol code specified in Navy Specification MIL-H-24148 (SHIPS 1965).

Wilson (1966) has attempted to standardize OSD symbols by selecting those most commonly used. Six symbols are recommended together with modifying indicators which make them applicable to almost any OSD usage. These are shown below in Figure 5. An example of an OSD using this format is shown in Figure 6. Additional information on OSD employment and format is found in NAVWEPS 18413A (1963).

2.2.4 Output. The effort thus far enables a number of device design decisions to be made. These include:

- Decision on the level of abstraction to be achieved in the trainee station displays and controls.

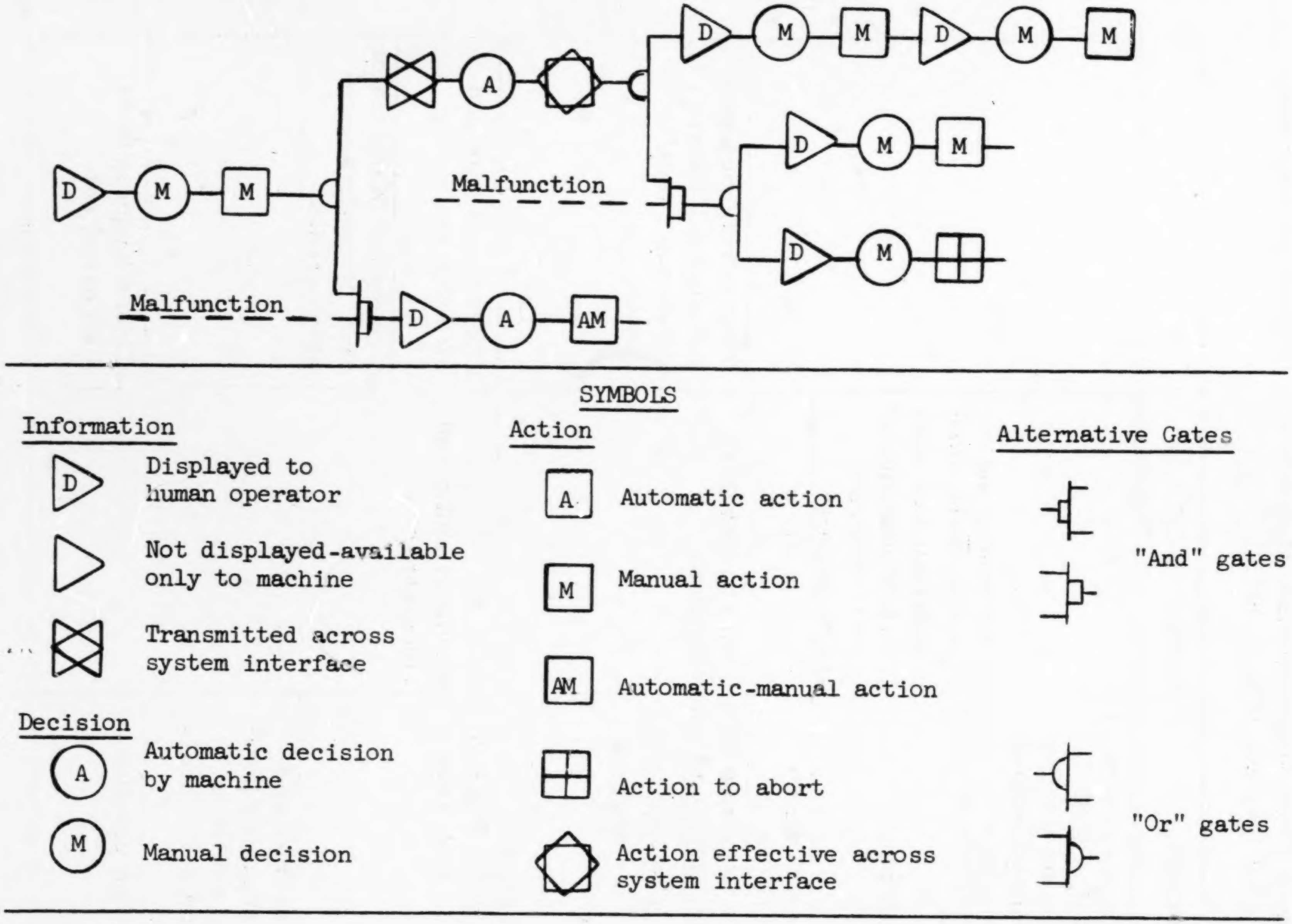

D
M
M
A
Malfunction
Malfunction
AM
SYMBOLS
Information
Displayed to human operator
Not displayed-available only to machine
Transmitted across system interface
Decision
Automatic decision by machine
Manual decision
Action
Automatic action
Manual action
Automatic-manual action
Action to abort
Action effective across system interface
Alternative Gates
"And" gates
"Or" gates

Figure 1. An IDA Diagram and Typical Symbols as Used in Analyzing Man-Machine Task Performance

TASK: Mating of a Rescue Submersible With a Downed Submarine (Distress)

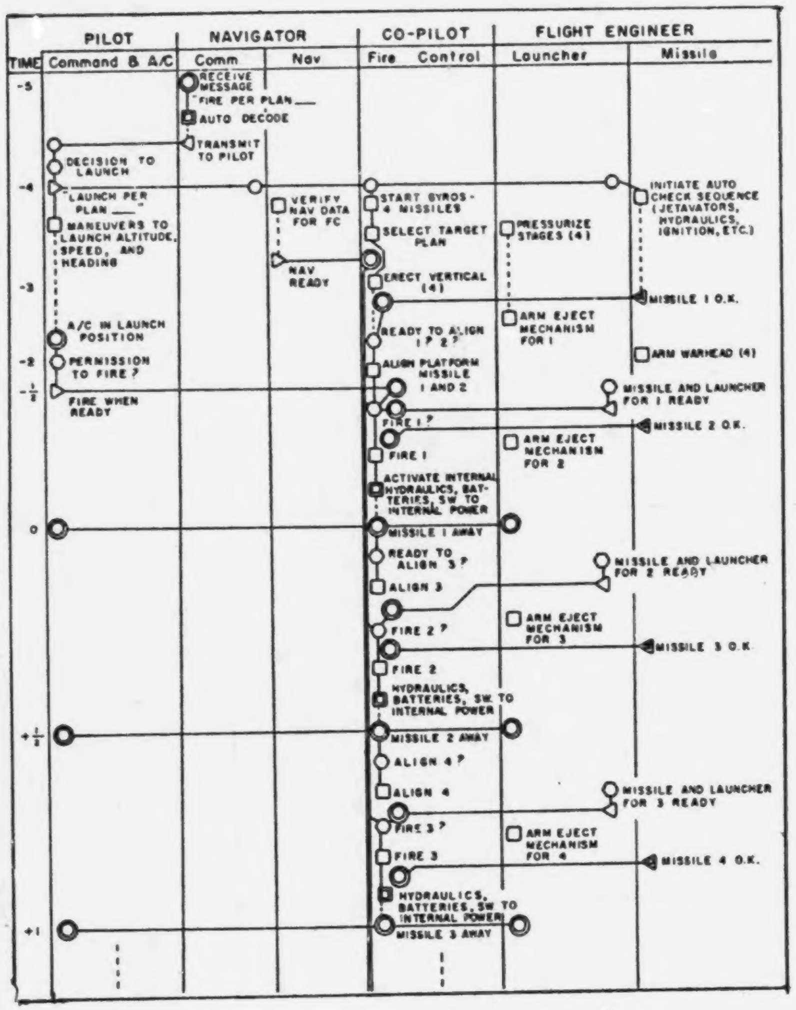
(Previous Task Accomplished: Approach to Distressed Submarine and Sensor Contact With Vehicle)

TIME (minutes)	PILOT	CO-PILOT	CREWMAN
0	Maneuvers rescue submarine (DSRV) to optimum position and orders drop of transponder		
1			
2		Drops transponder	
3	Hovers	Contacts distressed submarine and asks for crew and internal environment status report	
4			
5			
6			
7	Decides on hatch to mate with		
8	Orders crewman to don emergency gear and rig winch and casualty chute		Dons emergency gear and rigs midsphere winch and casualty chute
9	Decides on and drops ballast for descent to hatch		
10			
11			
12			
13	Maneuvers DSRV to mating hatch area	Monitors audio and video sensors	Pressurizes mid and aft spheres
14			
15			Checks out Manipulator arm controls and reports status
16			
17	Adjusts trim and propulsion for positioning DSRV on hull and holds position		
18			
19			
20	Maintains position		Clears hatch area of distressed sub
21			
22			

Figure 2. Multiple Activity Process Chart (Part 1 of 2)

TIME (minutes)	PILOT	CO-PILOT	CREWMAN
23	Maintains Position	Monitors audio and video sensors	Clears hatch area of debris with water jet and brush, cuts messenger buoy cable
24			
25		Activates and checks out mating sensors (lights, viewing optics, TV, mating hatch sonar	
26			
27			
28	Prepares for final descent and mating, deploys pre-mating subsystems	Monitors all displays and reports to pilot	Inspects visually the mating area through viewport and reports to pilot
29			
30			
31	Positions DSRV on hatch of submarine		
32			
33			
34			
35	Stabilizes DSRV for final mating, effects final airtight seal to hatch		
36			
37			
38			
39			
40	Verifies mating of DSRV with submarine (hull pressure)		
41			
42			
43			

Figure 2. Multiple Activity Process Chart (Part 2 of 2)


PILOT
NAVIGATOR
CO-PILOT
FLIGHT ENGINEER
TIME
Command & A/C
Comm
Nav
Fire Control
Launcher
Missile
-5
-4
-3
-2
$-\frac{1}{2}$
0
$+\frac{1}{2}$
+1
RECEIVE MESSAGE
"FIRE PER PLAN ___"
AUTO DECODE
TRANSMIT TO PILOT
DECISION TO LAUNCH
"LAUNCH PER PLAN ___"
MANEUVERS TO LAUNCH ALTITUDE, SPEED, AND HEADING
A/C IN LAUNCH POSITION
PERMISSION TO FIRE?
FIRE WHEN READY
VERIFY NAV DATA FOR FC
NAV READY
START GYROS - 4 MISSILES
SELECT TARGET PLAN
ERECT VERTICAL (4)
READY TO ALIGN 1? 2?
ALIGN PLATFORM MISSILE 1 AND 2
FIRE 1?
FIRE 1
ACTIVATE INTERNAL HYDRAULICS, BATTERIES, SW TO INTERNAL POWER
MISSILE 1 AWAY
READY TO ALIGN 3?
ALIGN 3
FIRE 2?
FIRE 2
HYDRAULICS, BATTERIES, SW. TO INTERNAL POWER
MISSILE 2 AWAY
ALIGN 4?
ALIGN 4
FIRE 3?
FIRE 3
HYDRAULICS, BATTERIES, SW TO INTERNAL POWER
MISSILE 3 AWAY
PRESSURIZE STAGES (4)
ARM EJECT MECHANISM FOR 1
ARM EJECT MECHANISM FOR 2
ARM EJECT MECHANISM FOR 3
ARM EJECT MECHANISM FOR 4
INITIATE AUTO CHECK SEQUENCE (JETAVATORS, HYDRAULICS, IGNITION, ETC.)
MISSILE 1 O.K.
ARM WARHEAD (4)
MISSILE AND LAUNCHER FOR 1 READY
MISSILE 2 O.K.
MISSILE AND LAUNCHER FOR 2 READY
MISSILE 3 O.K.
MISSILE AND LAUNCHER FOR 3 READY
MISSILE 4 O.K.

⬡ Operator decision (*e.g.*, proceed on basis of received information?).

□ Operator action (*e.g.*, throw switch).

▷ Information transmitted (*e.g.*, via phone circuit).

○ Information received (*e.g.*, voice command).

▣ Automatic action (*e.g.*, automatic checkout).

⊳ Information transmitted automatically (*e.g.*, missile checks, from checkout equipment to FC).

◎ Information received automatically (*e.g.*, signal light).

Vertical lines tie together sequential items; a dashed vertical line indicates a time delay in the sequence.
Horizontal lines represent information links between equipments and/or operators.
Rough time schedule is indicated in a separate column.
Numbers inside symbols may be used for reference to a key.

Figure 3. An Example of an Operational Sequence Diagram

(from Brooks, 1960)

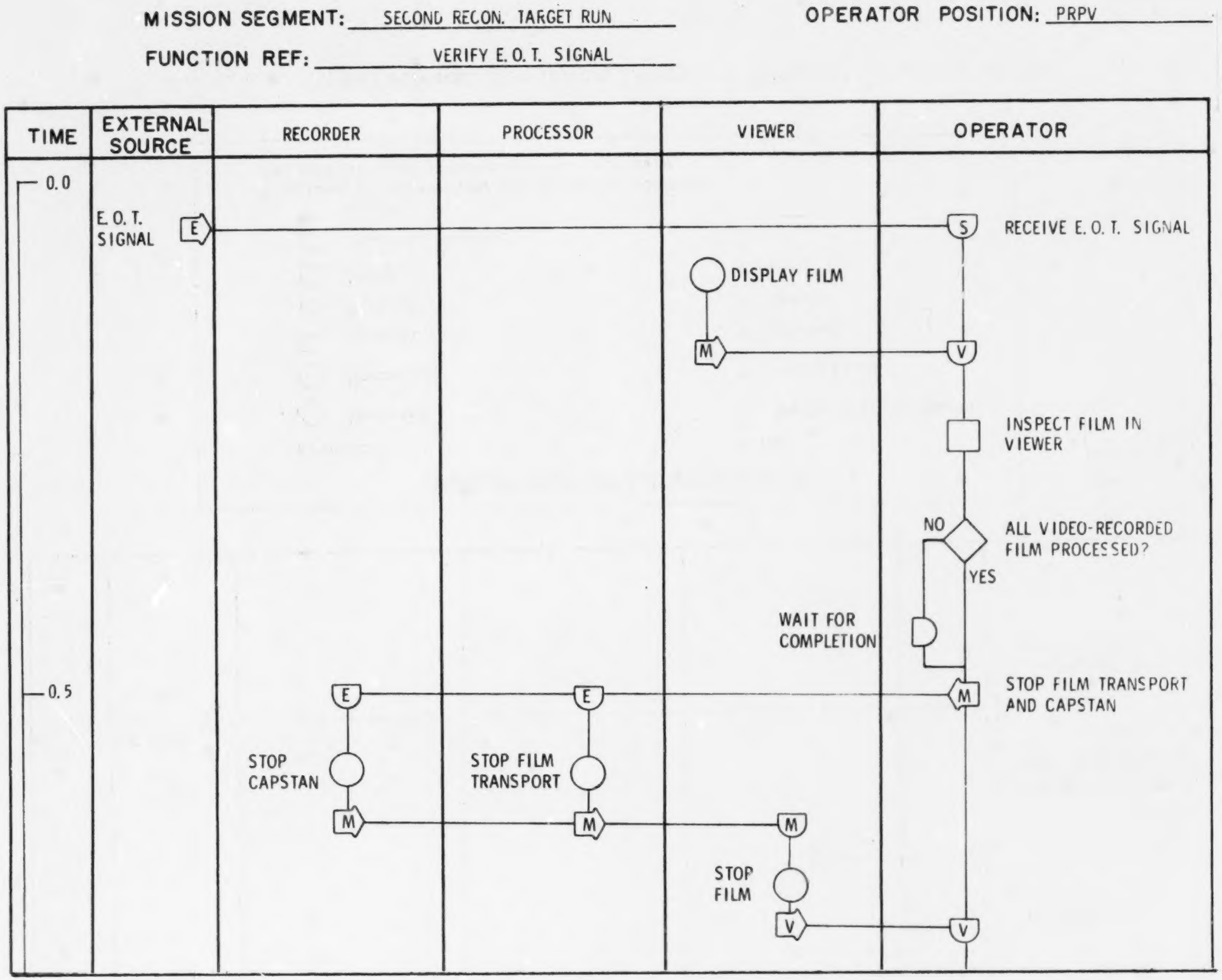

MISSION SEGMENT: SECOND RECON. TARGET RUN
OPERATOR POSITION: PRPV
FUNCTION REF: VERIFY E.O.T. SIGNAL
TIME
EXTERNAL SOURCE
RECORDER
PROCESSOR
VIEWER
OPERATOR
0.0
0.5
E.O.T. SIGNAL
E
S
RECEIVE E.O.T. SIGNAL
DISPLAY FILM
M
V
INSPECT FILM IN VIEWER
NO
ALL VIDEO-RECORDED FILM PROCESSED?
YES
WAIT FOR COMPLETION
E
E
M
STOP FILM TRANSPORT AND CAPSTAN
STOP CAPSTAN
STOP FILM TRANSPORT
M
M
M
STOP FILM
V
V

Figure 4. Operational Sequence Diagram Format (Part 1 of 2)

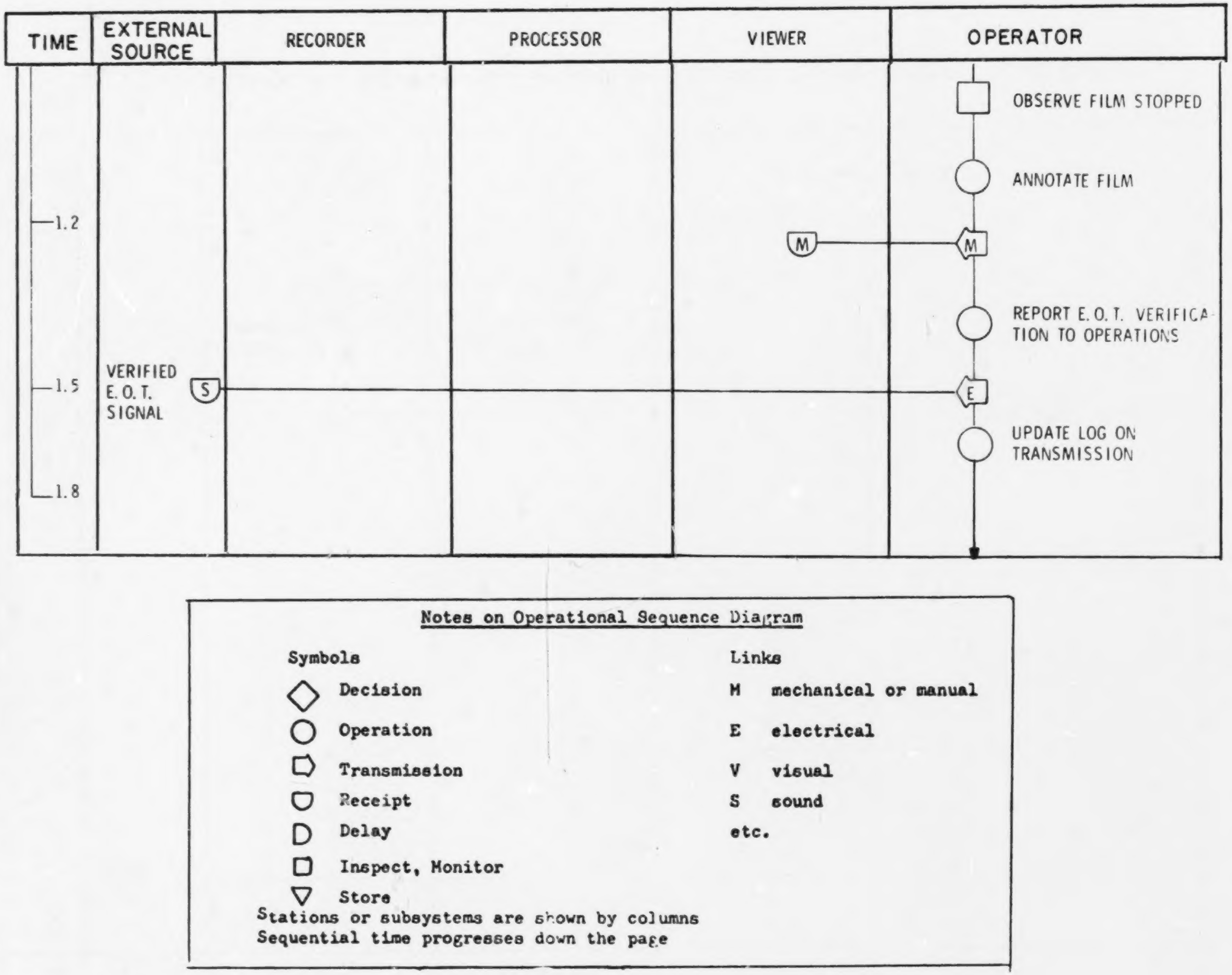

TIME
EXTERNAL SOURCE
RECORDER
PROCESSOR
VIEWER
OPERATOR
1.2
1.5
1.8
VERIFIED E.O.T. SIGNAL
S
M
M
E
OBSERVE FILM STOPPED
ANNOTATE FILM
REPORT E.O.T. VERIFICATION TO OPERATIONS
UPDATE LOG ON TRANSMISSION
Notes on Operational Sequence Diagram
Symbols
Decision
Operation
Transmission
Receipt
Delay
Inspect, Monitor
Store
Links
M mechanical or manual
E electrical
V visual
S sound
etc.
Stations or subsystems are shown by columns
Sequential time progresses down the page

Figure 4. Operational Sequence Diagram Format (Part 2 of 2)

BASIC FUNCTIONAL SYMBOLS

⇨	Transmission of Information	◡	Previously Stored Information
○	Receipt of Information	◇	Decision
▽	Storage of Information	□	Action

MODIFYING INDICATORS

When necessary to specify machine behavior, add a line across the bottom of the symbol, thus:

□	Human Action	⊟	Machine Action

When necessary to indicate storage of information on display to humans, insert a "D" indicator inside the "store" symbol, thus:

▽ D	Store information (manually as on a plot board)
▽ D	Store information (automatically as on a radar scope, indicator light, or readout)

When necessary to indicate an inverse meaning, add a diagonal line across the symbol, thus:

□	Action (yes, "go")	⧄	Inaction (no, "no-go")

When necessary to specify means of communication, insert an appropriate indicator inside "transmit" and "receive" symbols, such as:

E	Electric or Electronic		
V	Visual	SP	Sound-powered Phone
S	Speech	T	Touch

Figure 5. Suggested OSD Symbology
(from Wilson , 1966)

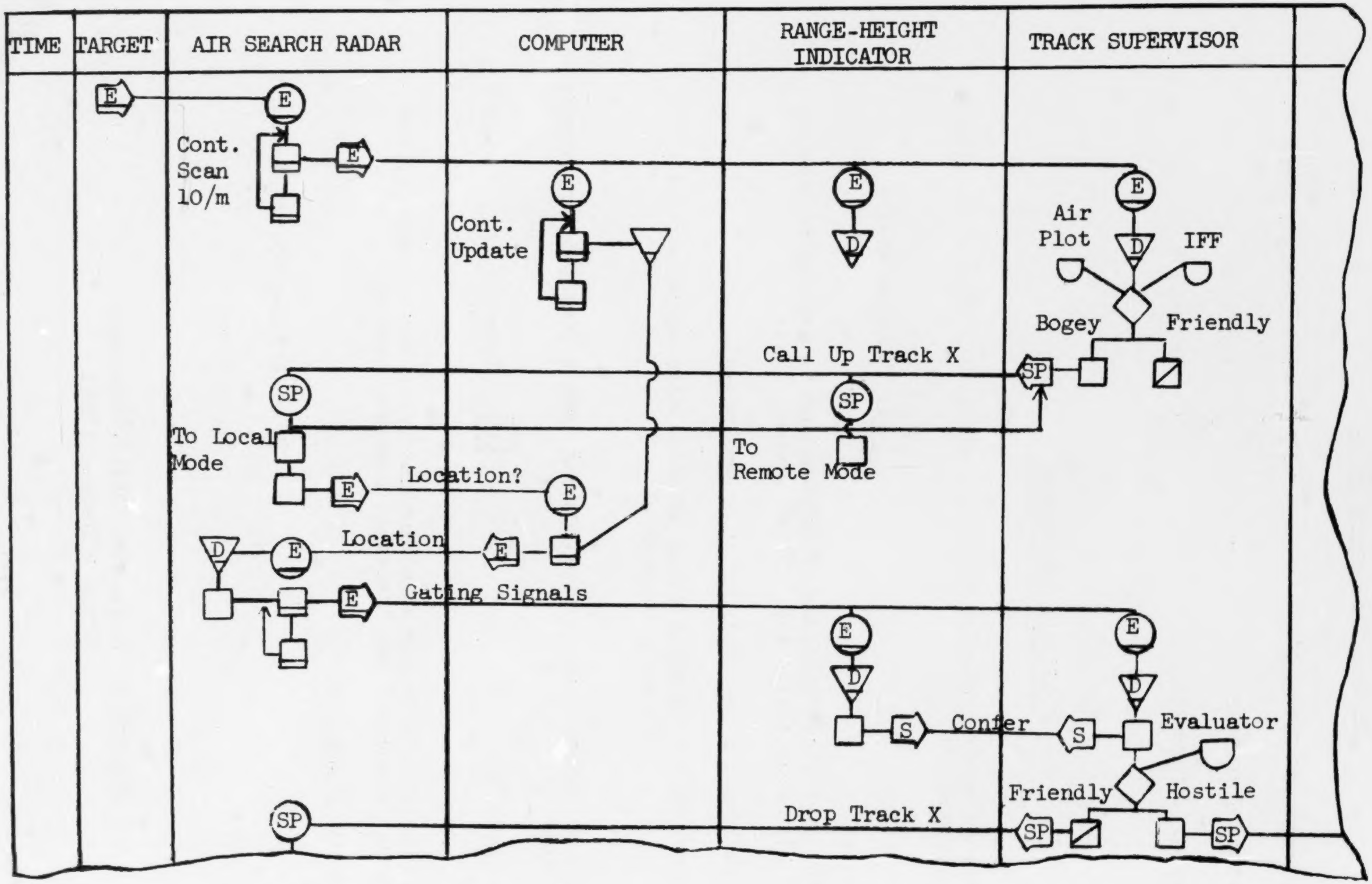

TIME
TARGET
AIR SEARCH RADAR
COMPUTER
RANGE-HEIGHT INDICATOR
TRACK SUPERVISOR
E
Cont. Scan 10/m
Cont. Update
D
Air Plot
IFF
Bogey
Friendly
Call Up Track X
SP
To Local Mode
To Remote Mode
Location?
Location
Gating Signals
S
Confer
Evaluator
Friendly
Hostile
Drop Track X

Figure 6. Example of Detailed Functional Analysis OSD
(from Wilson, 1966)

- Definition of training equipment requirements: system suites, equipment components for specific systems; or generalized components to provide for the range of mission requirements for universal/general training.

- Definition of key system components.

- Decisions on what components can be omitted and on those components that are not crucial to training.

- Description of key personnel positions.

- Definition of the range of mission activities to be accounted for in the device.

These analyses are the prelude to the analysis of human involvement in the training system and to the overall definition of the device configuration. The importance of this effort must not be minimized, for these activities provide a vital input to later analyses on design decisions leading to the specification of the functional characteristics of the operational environment to simulate for training.

2.2.5 Summary: Organizing Information on the Operational System. Becoming familiar with the operational system as a prelude to training device design is a simple and meaningful statement. No one would contest the logic that a fundamental understanding of the system in question and the kinds of training problems involved provides the groundwork for device design decisions. The manner of achieving this is something else. What and how much information is required and how difficult is it to obtain and organize the information, are the paramount questions. The answer is simple when in the form of a principle: gather that information which will provide a correct picture of which subsystems have the major influence on the total system. In other words, organize only the information which enables an evaluation of what operator tasks have high skill requirements, are importantly related to system effectiveness, and can yield improved performance through training. In essence, what is needed is information in a form which will facilitate determining the importance of task performance to system effectiveness.

Before we succumb to the lure of the graphic analysis techniques, let us reiterate that the purpose of these analytic efforts is to gain the system familiarization necessary to specify the characteristics of the synthetic training system under consideration, no more, no less. The OSD is recommended only to facilitate the understanding of the basic processes in system composition. The decision to do an OSD tends to insure an understanding of a system, in that the OSD structure demands a continuity in system flow, and establishes relationships between operators and equipment and between operators and tasks. It also serves as a visible basis for confirmation of the system description with operational personnel. To the extent that information on human involvement in the system is available (e.g., standard procedures, information flow sequences, operator functions and duties) then graphic techniques may not be required. (Typically, this is not the case since system documentation most often centers on equipment capabilities). OSD's are tailored to a specific requirement since a complex training device is a one-of-a-kind or at most, a few-of-a-kind endeavor. Although there are commonalities within classes of systems, the analysis is specific to the given system and is expensive in time and effort. Thus, the system familiarization phase must be organized to gain the necessary information most economically. This means that the need for elegant analyses must be justified in light of available information sources.

2.2.5.1 Research Issue. The issue of how much information is required and in what form for the system familiarization stage is not easily resolved. Available graphic techniques are used for various system design purposes. The OSD, for example, is used in prime system design to establish system requirements, to allocate man-machine functions, to determine sequences of operations, and to evaluate equipment and panel layouts and the design of workspaces. It is also used in personnel research and in training system design and utilization, although the purpose and emphasis is different in each case. Yet, OSD guidelines and formats are presented as if the method is invariant for any purpose. Guidelines on uses of analytic techniques relative to training requirements determination are needed, specifically, the uses of graphic analysis in the design of training systems (when to employ, how much and what kind of information to organize, and how the information is used as a base for further analysis of operator tasks).

2.3 PHASE 3: ANALYSIS OF TASKS INVOLVING HUMAN PARTICIPATION. Preparation has now been completed for an analysis of the tasks that people perform in the operational system, in order to define task structure relative to decisions about training. Task information provides a basis for determining whether or not training equipment is indeed necessary to support a training effort in the operational context (e.g., decisions on the need for a training device vs. the suitability of simple training aids for achieving defined training purposes). In instances where a training device need is justified, the development of the functional requirements for the simulator is based significantly on determinations of what the individual(s) must do in the operational situation. Thus, an understanding of the kinds or types of training to be accomplished is a straightforward requirement in the design process. The understanding of the training problem and the identified design pathway set the guidelines for the analysis of tasks; the system information provides the base from which the task analysis is derived.

The effort in this phase is geared to identifying and organizing the activities involved in job performance to enable decisions about characteristics of the training system. This is done at a level of detail which will assist in the identification of design alternatives to achieve the purpose of training. Nothing more than this is needed.

Decisions on training system design are made in successive stages. Correspondingly, system and task information is gathered, organized, and refined in a like manner. Two classes of requirements are accomplished in this phase: the definition of the operational task structure; and the definition of training objectives.

2.3.1 Operational Task Structure. An effective task structure analysis should have a training hardware orientation with emphasis on the man-equipment interfaces. It is accomplished in sufficient detail to identify design options available to meet the purpose of the training system. The hardware orientation is necessary also to insure that the functional design selected has the flexibility to accommodate needed changes in the training system that inevitably arise from experience with the device (including changes in operational doctrine, etc.), once it is in operation. To be avoided is the exercise of doing an analysis which is lengthy and time-consuming and elegant in format, but which provides unnecessary information for translating task description data into a set of functional specifications for device design.

Task organization is accomplished in operational terms--what each trainee is accountable for across the range of training missions/events. The analysis is conducted only to the task level which provides the information necessary for training decisions. Most often, further refinements in detail are extravagant of time and effort and contribute very little more to the design decision process.

Decisions on training system design are made in successive stages, correspondingly, system and task information is gathered, organized and refined in a like manner. Task analysis progresses in stages, undergoing continual refinement to achieve the definition of task structure required for making training design decisions.

The starting point is the system descriptive information and the defined equipment complexes of the operational system. At this point in the design cycle the following has already been determined.

- Decision on the level of abstraction, i.e., the realism to portray in the training system.

- Definition of system suite--those complexes of equipment to be duplicated in the trainer (and those related subsystems that are not relevant to the device under consideration).

- Decisions on key system components with dynamic fidelity implications.

- Decisions on what functions of the relevant operational system are to be omitted.

- Decisions on what components of the training system are not crucial to the training, but serve to support the training and thus are included in design (secondary emphasis).

- Description of the key personnel positions in the training system.

- Definition of the range of mission activities to be included in the training system. For example, in ASW operations, it could involve one and two destroyers in screen and SAU operations, weapon delivery of ASROC, torpedoes and DASH; coordinated aircraft operations involving VECTAC's, etc.

The effort begins with a list of positions in the system and a description of the operational tasks pertinent to each position. The progression for developing the task inventory starts with an individual position (and where applicable, the subsystem in which it is imbedded) and defines the functions performed, then the task areas, and finally the operational activities in each task. Information is gathered from various sources: observing tasks performed by job incumbents; reviewing documents; and discussions with subject matter experts.

Thus, the task analysis is in the systems context and only for that portion of the system that is to be represented in the device. The analysis should yield a listing and grouping of task statements to provide a structure which defines the performances to be accomplished in the training system. The following information is organized (i.e., as minima):

- The activity elements which make up the task.
- The trainee(s) involved in the activity.
- Equipments required (displays, controls,.communications).
- Skills and knowledges required in performance.
- Any unusual conditions of performance.

2.3.1.1 Representative Task Analyses. There is considerable variation in task analysis techniques, in part resulting from level of detail and emphasis and in part due to the specific design situations to which they are applied. The most common task analysis techniques employ tabular formats which identify some or all of the following: job task segments; personnel breakouts (in multi-man situations); equipment involved; conditions of performance; and skills and knowledges required in task performance. Commonly, the activities are presented in a normal or logical sequence of occurrence (see, for example, the format used in Section IV of this report for destroyer ASW activities). Time information may be implied or provided by a time scale or by statements of time involvement. Considerable numbers of task analyses have been conducted during the last two decades and much published evidence of the technique exist. Several sources in the literature are identified here to provide the reader with a cross-section of the thinking about, and application of task analysis techniques (see, for example, Miller (1962), Cotterman (1960), Smith (1965), Rundquist (1967, 1970), NAVWEPS (OD18413A)). Since task analysis techniques and information content are so varied, representative analyses are shown below to acquaint the reader with a range of techniques used and with an idea of the effort that must be expended. The examples have been selected to emphasize the differences in various task analysis techniques.

2.3.1.1.1 Chenzoff and Folley--The method of Chenzoff and Folley (1965) is an attempt to systematize task information relative to the design of training devices. This task analysis method was designed as a major stage in the Training Situation Analysis (TSA) process developed by the Naval Training Device Center (Bertin, 1965) for defining the specifications for training support equipment. The Chenzoff and Folley method develops a progression from gross to specific task information. The stages in the task analysis and the kinds of data obtained are summarized below.

Stage	Analysis Unit	Data Obtained
System block analysis	Total system	Major system operations arranged in sequence and type
Task time charts	Operating stages of the system (or the total system)	Task identification and relationships among tasks
Functional task descriptions	Tasks	Activities within tasks and relationships among activities
Behavioral details descriptions	Activities within tasks	Detailed characteristics of activities

a. System Block Analysis

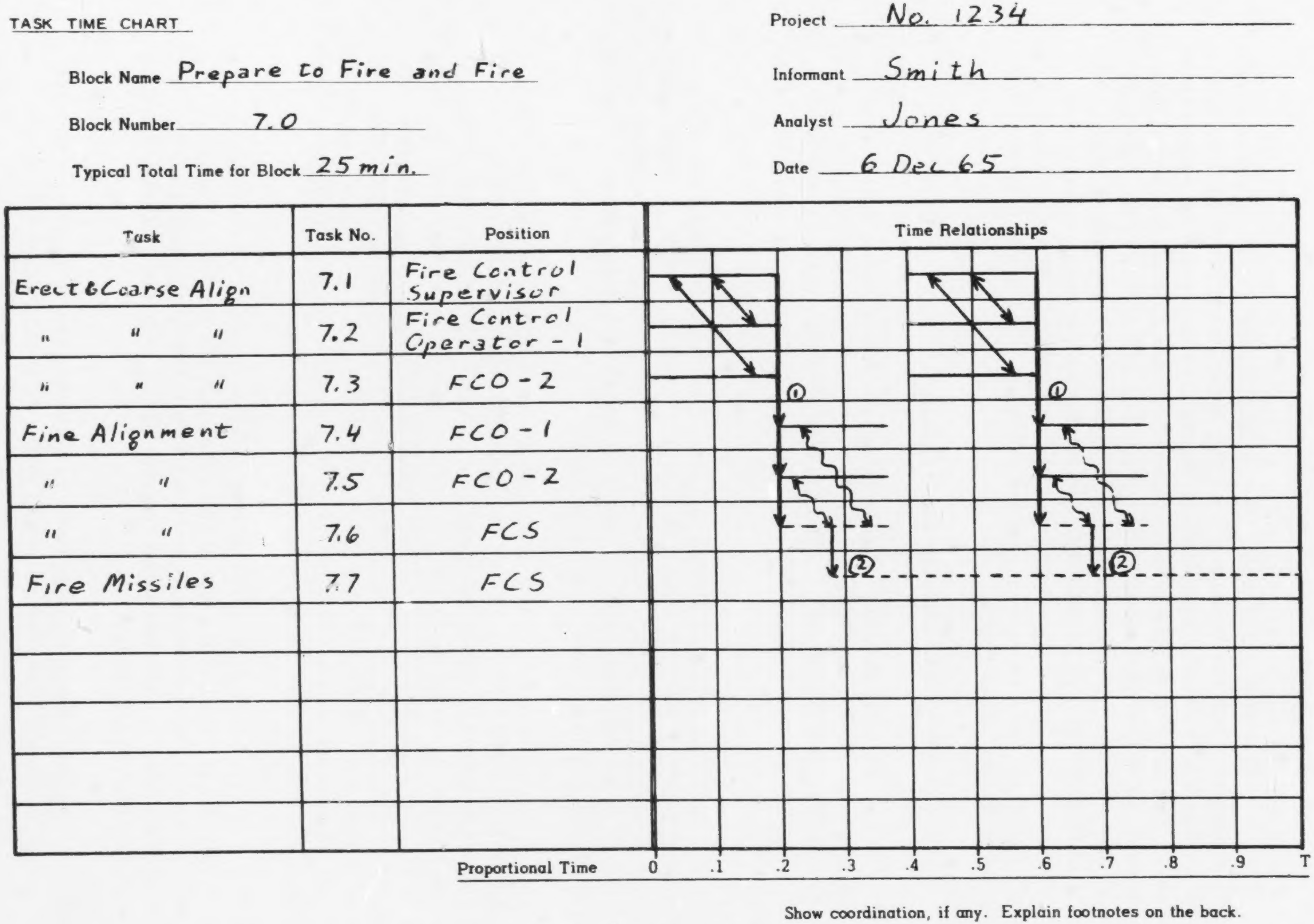
System tasks can be identified and listed directly or a block analysis can be accomplished which is simply a sequential listing of major blocks of tasks or system operations into which a system can be partitioned.

Example:

	Block	Remarks
1.0	Accept and inspect weapon	
2.0	Assemble weapon	Follows Block 1
3.0	Check out weapon	Follows Block 2, 9 or 10
4.0	Position weapon	Follows Block 3
5.0	Check assigned targets within range	Follows Block 4
6.0	Establish Ready-to-Fire condition	Follows Block 5
7.0	Prepare to fire and fire	Follows Block 6
8.0	Travel to target	Follows Block 7
9.0	Scheduled maintenance	On regular schedule
10.0	Unscheduled maintenance	As required

b. Task Time Charts

In this stage, the tasks are identified, the time and coordination requirements for the tasks, and any adverse conditions surrounding performance are established. In the accompanying task time chart, Figure 7, each task and the operators are listed; time lines are shown to indicate the period of time consumed by each task. Coordination between and among people is shown by diagonal arrows and wavy lines (a dashed line indicates intermittent coordination). Any adverse conditions (i.e., environmental or situational factors which degrade task performance) are also recorded.



TASK TIME CHART

Block Name Prepare to Fire and Fire

Block Number 7.0

Typical Total Time for Block 25 min.

Project No. 1234

Informant Smith

Analyst Jones

Date 6 Dec 65

Task	Task No.	Position
Erect & Coarse Align	7.1	Fire Control Supervisor
" " "	7.2	Fire Control Operator - 1
" " "	7.3	FCO - 2
Fine Alignment	7.4	FCO - 1
" "	7.5	FCO - 2
" "	7.6	FCS
Fire Missiles	7.7	FCS

Time Relationships
①
①
②
②
Proportional Time
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
T

Show coordination, if any. Explain footnotes on the back.

Figure 7. Task-Time Chart
(from Chenzoff and Folley, 1965)

c. Functional Task Description

The activities and interrelationships within tasks are defined in this stage. Determined here are the time to perform tasks, the activities within tasks, the proportion of attention each activity requires of the operator, the contingencies (i.e., things that may disturb normal performance such as equipment malfunction, human error, unusual external situations) and any adverse conditions that apply to an individual task. Six classes of task activity are identified: procedure following, continuous perceptual-motor activity, monitoring, communicating, decision-making or problem-solving, and non-task related activity. Figure 8 provides the functional task description form.

d. Behavioral Details Description

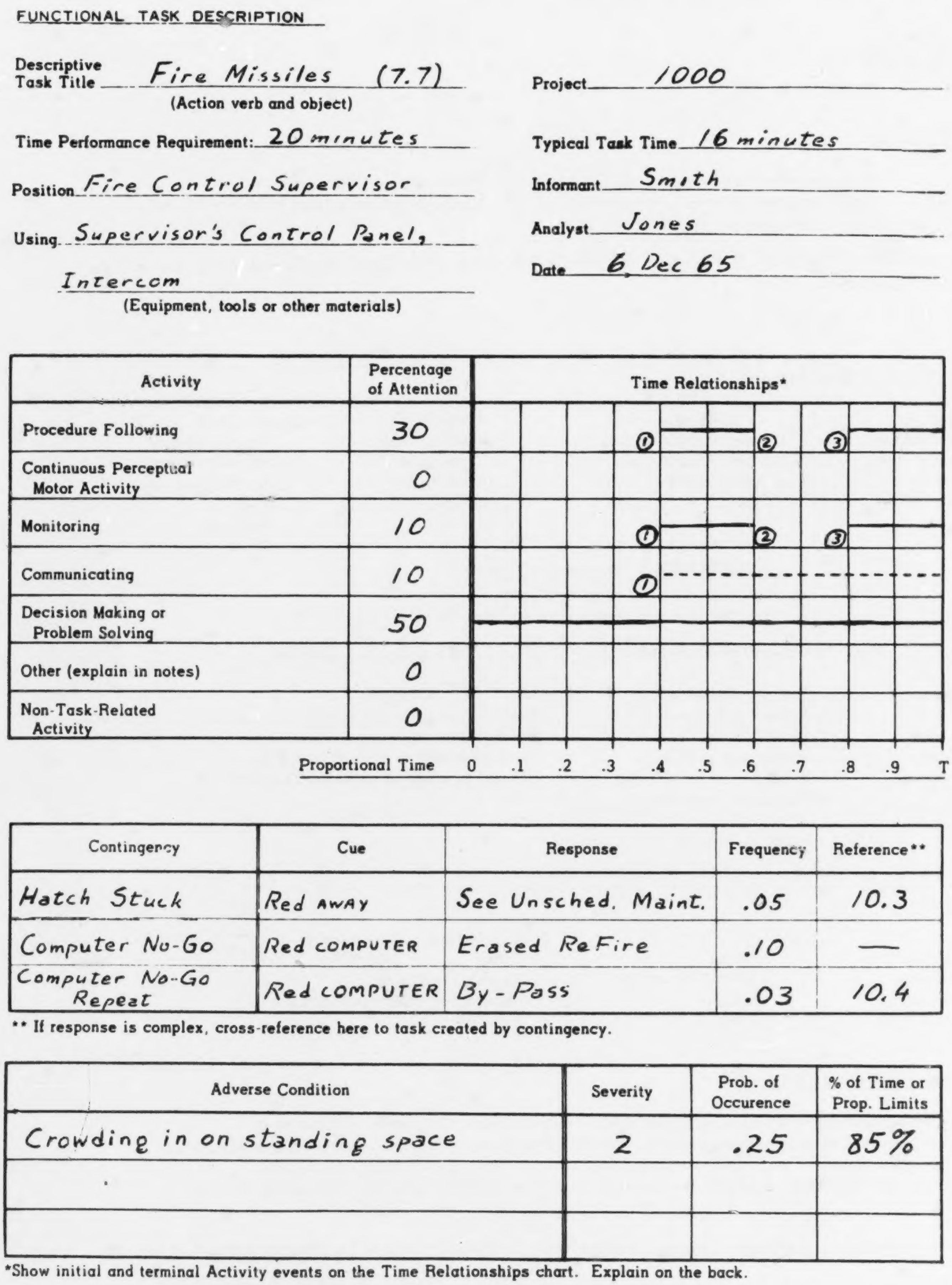
The most detailed level of task description is developed at this stage of the analysis. Estimated here are: trainee capability to perform the tasks, the difficulty of the training problem associated with each task, and the level of performance that can be expected after training (see Figure 9).

Chenzoff and Folley believe this approach will enable a precise description of the relevant tasks in a system and will provide the information necessary to make base decisions about the gross features of the ultimate training program (i.e., the Functional Training Requirements phase in the TSA process mentioned earlier).

2.3.1.1.2 Goodyear--Another example is the technique employed by the Goodyear Aerospace Corporation in determining Submarine Casualty Control Training Requirements (Goodyear, 1966). This study determined the critical factors to be simulated for team training in submarine casualty control by an analysis of crew position responsibilities and a task analysis of submarine casualty sequences. Table 1 shows an example from the training requirements analysis and crew position responsibilities; Table 2 provides an example from a sequence and task analysis; and Table 3 defines critical factors and the skill and knowledge requirements.

2.3.1.1.3 Part-Task Analysis--Task Analyses are also conducted specific to part-task requirements in the total job structure. Table 4 provides an example which is concerned with determining visual and motion cue requirements for tasks that must be simulated in a tactical flight training device (AH-56A helicopter).

2.3.1.1.4 Siegel--Another approach to defining training requirements was developed by Siegel and Federman (1970) for analyzing the tasks involved in the tactical coordinator function in the P3C/VSX aircraft. Task structuring was accomplished by the technique of intellective load analysis



FUNCTIONAL TASK DESCRIPTION

Descriptive Task Title *Fire Missiles (7.7)*
(Action verb and object)

Project *1000*

Time Performance Requirement: *20 minutes*

Typical Task Time *16 minutes*

Position *Fire Control Supervisor*

Informant *Smith*

Using *Supervisor's Control Panel, Intercom*
(Equipment, tools or other materials)

Analyst *Jones*

Date *6 Dec 65*

Activity	Percentage of Attention	Time Relationships*
Procedure Following	30	① ② ③
Continuous Perceptual Motor Activity	0	
Monitoring	10	① ② ③
Communicating	10	①
Decision Making or Problem Solving	50	
Other (explain in notes)	0	
Non-Task-Related Activity	0	

Proportional Time 0 .1 .2 .3 .4 .5 .6 .7 .8 .9 T

Contingency	Cue	Response	Frequency	Reference**
Hatch Stuck	Red AWAY	See Unsched. Maint.	.05	10.3
Computer No-Go	Red COMPUTER	Erased ReFire	.10	—
Computer No-Go Repeat	Red COMPUTER	By-Pass	.03	10.4

** If response is complex, cross-reference here to task created by contingency.

Adverse Condition	Severity	Prob. of Occurence	% of Time or Prop. Limits
Crowding in on standing space	2	.25	85%

*Show initial and terminal Activity events on the Time Relationships chart. Explain on the back.

Figure 8. Functional Task Description Form (from Chenzoff and Folley, 1965).

BEHAVIORAL DETAILS DESCRIPTION BLOCK NO. 7.0 TASK NO. 7.7

Procedure Following

[✓ Fixed] – Number of steps in procedure 20 Number of SB steps 2

___Branched – Maximum number of steps in procedure ______ Number of possible steps which are SB ______

Describe below the kinds of SB steps involved:

If Computer lights red after Erase and ReFire, estimates needle fluctuation.

Continuous Perceptual-Motor Activity None

Type

___Guiding a vehicle
___Operating remote manipulators
___Keeping cursor on target
___Other______

Displays

___Direct or window view
___Scope or instruments
___Optical system
___Other______

Error tolerance or accuracy required: ______

Controls

___Steering wheel
___Tracking handle
___Handwheels
___Other______

Control-Display Relationship

___Position control
___Velocity control
___Acceleration control
___Lag
___Backlash
___Other______

Monitoring

Object or signal to be monitored: Display Panel Lights

Display

___Scope
___Window view
[✓ Instruments]
___Optical system
___Sounds
___Other______

Relevant Attribute

___Movement of object or signal
___Appearance of object or signal
[✓ Change in object or signal]
___Other______

Other Data

Estimated frequency of events: ______
Search area: ______
Are events easy to detect? yes
If "no", how should detection be made?

Communicating

Media

[✓ Radio or telephone]
___Direct verbal
___Direct observation
___Written or printed English
___Video
___Electro-mechanical displays
___Other______

Special Knowledge Requirements None

___Code ___Format
___Keyboard operation
___Operation of special equipment (Specify)

Decision Making and Problem Solving

___The operator considers only one of several available courses of action. He bases his action on a rule-of-thumb, special knowledge or experience, or memory of what action has proven successful in the past.

___Reasonable alternatives are generated, considered, and rejected, until an acceptable one is found.

[✓ Most possible alternatives are known by the decision maker or problem solver, and all reasonable ones are evaluated.]

Describe what the decisions or problems consist of and the kinds of information used in reaching the decision or solution:

Basic signal flow through parallel Select and Target channels.

Figure 9. Behavioral Details Description Form (from Chenzoff and Folley, 1965)

TABLE 1. TRAINING REQUIREMENTS ANALYSIS AND CREW POSITION RESPONSIBILITIES

I - CASUALTY(IES): PLANE AND RUDDER FAILURES

A - PERSONNEL: HELMSMAN, STERN PLANESMAN, DO, OOD, COW, OFF-LOOKOUT (OR LEE HELMSMAN)

B - PART TASK GROUPING

1. HELMSMAN RESPONSIBILITIES

The helmsman responsibilities are:

1. Select control mode.
2. Select course and depth on AMC control panel.
3. Ring up ordered engine bells and acknowledge orders.
4. Control (normal) rudder to gain and maintain ordered course.
5. Control (normal) fairwater planes at moderate to shallow depth to reach and maintain ordered depth.
6. Monitor indicators to ensure correct operation of indicators, fairwater planes, and rudder and to ensure correct operation of the ship:

   Combined instrument unit indicators are gyro course, rudder angle, depth, trim angle, depth error, depth rate, and course error.

   Other indications are deep depth gage, shallow depth gage, digital depth indicator, speed indicator, engine order indicator, gyro course indicator, fairwater planes angle (normal and emergency), rudder angle (normal and emergency), and Magnesyn Indicator.
7. Notify DOOW of improper indications or failure.
8. Test periodically plane and rudder control (both normal and emergency modes).
9. Switch plane and rudder control to emergency power, activating power transfer pilot valves (or 700 psi air in case of 594 class ships) if required.

TABLE 1. TRAINING REQUIREMENTS ANALYSIS AND CREW POSITION RESPONSIBILITIES (Continued)

10. Test and operate planes in rate control (emergency power).

11. Request the lee helmsman to man emergency steering station.

12. Request lineup of hydraulic system for emergency positioning pump operation: (a) fairwater planes - lee helmsman, (b) stern planes and rudder - aft auxiliary electrician on phones; engine room upper level watch or machinery watch supervision on controls.

13. Exercise combined control of steering and planes using single stick (optional task).

14. Open or close valve, as appropriate, to operate or isolate shallow depth gage. Depth limit for safe gage operation is about 200 ft.

15. Acknowledge and report fulfillment of orders by OOD and DO.

16. Operate fairwater planes to compensate for stern plane failure or as directed by the DO.

(Responsibilities are also defined for the: stern planesman, duty officer, OOD, Lee Helmsman and COOW.)

(from Goodyear, 1966)

TABLE 2. SEQUENCE AND TASK ANALYSIS

C - FAIRWATER PLANES FAIL ON DIVE

1. RECOGNITION

a. Initial Conditions - Diving officer (DO) and/or planesmen are cognizant of ordered and actual speed, depth, depth rate, attitude, turn rate, trim, and hydraulic system status.

b. Detection

(1) Detection of Impending Casualties - BCPO notes abnormal hydraulic indications.

(2) Detection of Existing Casualties - If depth change is ordered, DO and planesmen note that the plane angle indicators do not respond or are erratic. This is followed by feel and indicated attitude and depth changes; lag varies from 0.5 sec to 5.0 sec. Other indications may be a hydraulic or electric alarm or an audible change in the noise of hydraulic fluid flow.

If a steady state is desired, planesmen note that the angle indicator is not consistent with control position. Both the DO and planesmen note erratic indications or hydraulic or electric alarm. Both subsequently note "feel" and indicated attitude changes; lag varies from 0.5 sec to 5.0 sec. SP may have difficulty in reaching and holding ordered attitude.

c. Verification

The DO, supported by detailed H and BCPO checks, verifies that a fairwater plane casualty exists. DO immediately checks emergency fairwater plane indicator and assesses trim and maneuver effects. Checks by DO involve short delays, checking hydraulic control in the emergency mode, and checking changes in ship's speed and attitude.

2. DECISION MAKING (DO/OOD)

a. Ship Characteristics - Rate of change and current values of speed, depth, attitude, and turn and plane angle are noted.

b. Crew Characteristics - Crew capability, state of training, physiological/psychological condition, and reaction time are assessed.

c. System Status - Status of essential ship systems is assessed. DO assesses stern planes, hydraulics, and MBT blow. OOD assesses

TABLE 2. SEQUENCE AND TASK ANALYSIS (Continued)

stern planes, hydraulics, MBT blow, rudder, propulsion, engine order telegraph, 1 MC and 7 MC, and sound-powered phone.

d. Recall Appropriate Data - Special instructions, ship's standing orders, and other constraints, are recalled, for example, minimum depth, surface-ship activity, and ice overhead.

e. Recall Available Courses of Action - The available courses of action are stern planes rise, fishtail rudder, emergency back, MBT blow, emergency control, manual control, correct fairwater, plane problem, and none.

f. Data Collation - The information of 2a through 2d are collated against alternatives of 2e.

g. Course of Action Selection - Course of action is selected from 2f.

h. Command Decision - DO receives direction from OOD and modifies or retains decision of 2g.

3. CORRECTIVE ACTION

a. Basic Sequence - DO orders stern planes positioned to minimize depth excursion and OOD notifies engine room of failure.

b. Representative Alternative Actions - Depending on depth, tactical situation, and special instructions the DO/OOD may elect to avoid noise or broaching by some combination of (1) delay blow MBT; (2) speed all stop, then back full; (3) fishtail rudder; and (4) flood negative.

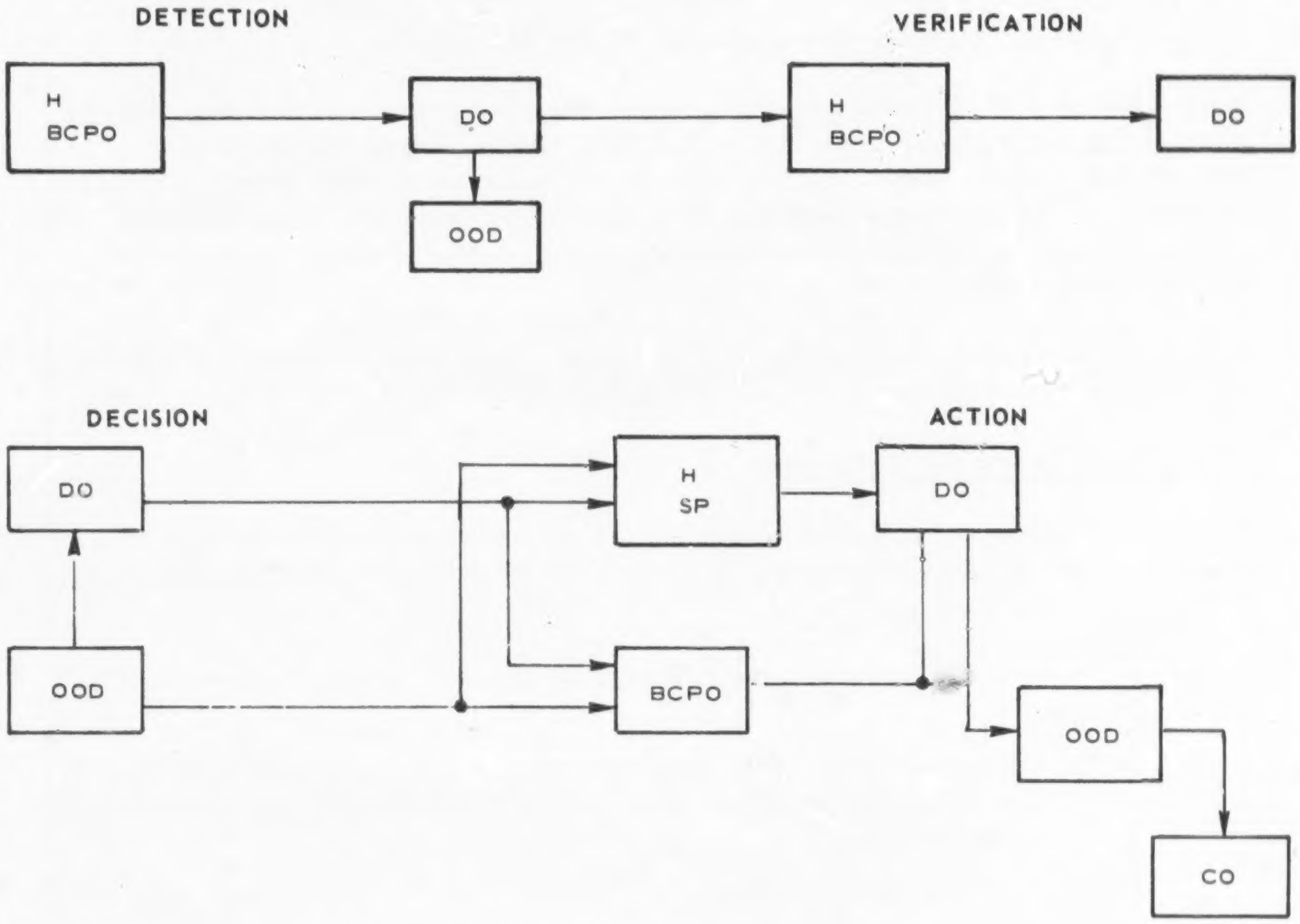
If fairwater plane fails at a small angle, at moderate or shallow depth and low ship angle, DO/OOD may elect to attempt to free the fairwater planes before employing the stern planes.

If hydraulic failure is indicated and ship conditions permit, DO/OOD will elect to have planesmen switch hydraulics to emergency or the manual mode as the primary initial action.

If indicator failure only, DO/OOD will elect to have planesmen use emergency indicator only. The DO may have phones manned in engine room to monitor fairwater plane ram indicator.

TABLE 2. SEQUENCE AND TASK ANALYSIS (Continued)

4. INFORMATION FLOW DIAGRAM


DETECTION
H
BCPO
DO
OOD
VERIFICATION
H
BCPO
DO
DECISION
DO
OOD
H
SP
BCPO
ACTION
DO
OOD
CO

5. FOLLOWON ACTION/FEEDBACK

a. Results - Indication of Results of Initial Action

(1) Operator Response - Personnel who will indicate satisfactory execution of orders and/or status of systems for which they are responsible are the DO, EOOW, H. SP, and BCPO/COW.

(2) CO Response - The CO may, at his option, elect to supplement or modify the actions of the DO or OOD.

(3) Ship Response

(a) Variables of 2a and 2c.

(b) Variable and negative tank status

b. Determine Supplemental Actions Required - Possibilities include change from limited action of 3b to full action of 3a.

TABLE 2. SEQUENCE AND TASK ANALYSIS (Continued)

c. Indication of Followon Results

(1) CO Response (Directives) - The CO may, at his option, elect to supplement or modify the actions of the DO/OOD.

(2) Ship Status - Followon conditions of recovery procedure are slight change in buoyancy, decreasing depth, decreasing down angle, speed ≤ 5 knots, and depth ≅ 400 ft (assuming ascent from deeper depths). Followon conditions of alternate recovery procedures are positive buoyancy, decreasing depth, decreasing speed, and decreasing down angle.

d. Determine Action Required to Complete Recovery - Desired (safe) operating envelope and action required are identified.

e. Complete Casualty Recovery

Representative action for completion of recovery procedures is to adjust stern planes and trim to level off at desired depth consistent with tactical situation.

Representative action for completion of alternate recovery procedures are

1. Secure blow and adjust trim to level off at a desired depth consistent with tactical situation
2. Engines, all stop
3. Rudder amidship
4. Blow and vent negative (or hovering tanks).

Final action is to rig for ship operation within a safe operating envelope.

(from Goodyear, 1966)

TABLE 3. CRITICAL FACTORS AND SKILLS/KNOWLEDGE REQUIREMENTS

Training Category	Critical Factors*	Skills/Knowledge*
I. Ship command and control	1. Immediate detection of plane or rudder casualty symptoms.	1. To ensure high degree of tracking capability by planesmen so that cues of malfunction from indicators, control system, or ship feel are not confounded with erratic or improper planes or depth control.
	2. Rapid discrimination between indicator failure, electrohydraulic failure, and mechanical failure on diving panel or BCP.	2. To develop in planesmen and DO's proper scanning habits and ability to shift attention among available indicators, thus avoiding mesmerization by one indicator or tunnel vision.
	3. Rapid corrective response implementing only action required to recover from casualty, minimizing effect on satisfaction of mission requirements, e.g.: (a) if depth indicator fails, use emergency indicator; (b) if normal hydraulic mode fails, operate in rate control; (c) if fairwater planes jam, compensate with stern planes; (d) if rudder jams, reduce ship speed and compensate for attitude change with planes.	3. To develop in planesmen and DO's capability to rapidly switch mental sets from one appropriate for normal automatic maneuvering control (AMC), or one-man control to one appropriate for emergency action. This includes prompt and discriminating reaction to alarms, abnormal indications, or abnormal ship motion.
		4. To develop in planesmen and BCPO perceptual motor capability to shift to alternate modes of operation, such as rate control, manual overrides for emergency blow or plane control, and local (emergency) manual control of planes, rudder, and vents.
		5. To ensure in DO's ability to analyze and maintain trim control so that cues of malfunction from indicators, control system, or ship feel

TABLE 3. CRITICAL FACTORS AND SKILLS/KNOWLEDGE REQUIREMENTS (Continued)

Training Category	Critical Factors*	Skills/Knowledge*
	4. Follow up ship control corrective action for stern planes fail on dive or flooding to achieve safe depth minimizing incompatibility with tactical situation.	are not confounded with heavy condition, down angle, up angle, or list due to improper or unknown trim. 6. To develop in planesmen ability to recognize, diagnose, and initiate appropriate corrective responses for stern plane, fairwater planes, and rudder casualties.
	5. Avoidance of confusion in interpretation of casualty symptoms by proper scanning and monitoring of depth, steering, speed, and BCP indications and by proper trim analysis and control.	7. To develop in planesmen ability to recognize, diagnose, and direct corrective action for depth and depth rate control problems due to indications of stern planes, fairwater planes, or rudder casualties. 8. To develop in DO's ability to initiate ship control actions in response to general emergencies, alarms, and as directed by OOD. This includes emergency surface, depth change for emergency ventilation, and depth change to ordered depth.
	6. Immediate recognition of failure of controls being used in ship recovery and use of alternative modes of activation; e.g., manual activation of pilot control valves for planes and emergency blow, lineup and use of local hydraulic valves for	9. To develop in OOD's/conning officers ability to scan and monitor ship control indications and BCP indications and evaluate ship performance to detect abnormal ship status, to monitor BCP operator and DO for performance that is inconsistent with ship safety and tactical situation.

TABLE 3. CRITICAL FACTORS AND SKILLS/KNOWLEDGE REQUIREMENTS (Continued)

Training Category	Critical Factors*	Skills/Knowledge*
	planes, depth control and steering using rate-control mode, and local MBT vent control. 7. Sound-powered phones manned for local control of vents, stern planes and rudder.	10. To develop in DO's and OOD's appreciation of safe operating envelope for ship combining such factors as depth, speed, buoyancy power-plant lineup, depth rate, and tactical situation. Demonstrations show relationship between initial conditions and seriousness of casualty effects.
	8. OOD receives current information on general emergencies, such as flooding and fire and power plant.	11. To develop in DO's and OOD's understanding of various corrective actions and combinations thereof to include effect of alternate actions on recovery and limitations and implications of use of recovery actions.
	9. Immediate decision and initiation of emergency blow to surface or come to safe depth upon recognition of stern plane fail on dive or serious flooding.	12. To develop in OOD's skill to initiate expeditiously proper casualty control procedures. 13. To develop in stern planesmen, helmsman, BCPO, DO, and OOD skill in evaluating the progressive effects of recovery action and performance of follow-up action necessary to restore safe operating envelope.
	10. Immediate decision and initiation of depth change including preparation to emergency ventilate as appropriate to fire, atmospheric contamination,	14. To exercise the control team in effective interaction and communications. 1. To ensure all personnel have knowledge of nearest location of communications/alarms from any location in all levels of each

TABLE 3. CRITICAL FACTORS AND SKILLS/KNOWLEDGE REQUIREMENTS (Continued)

Training Category	Critical Factors*	Skills/Knowledge*
	or radiation casualty.	compartment.
	11. Effective control team interaction and communications.	2. To develop in all personnel knowledge of all combustibles or electrical sources of fire in any part of their assigned watch station.
II. Fire recognition, isolation, and reporting	1. Immediate sounding of alarm.	3. To develop in watchstanders knowledge of equipment arrangement, controls, and location for isolation of electrical equipment or combustible materials involved in a fire.
	2. Rapid compartment isolation.	
	3. Rapid isolation of electrical equipment involved or of materials feeding fire.	4. To develop in all watchstanders knowledge of location of fire extinguishers, protective gear, breathing masks in all compartments.
		5. To develop in watchstanders ability to judge the severity of the fire.
	4. Determination of type of fire and choice of proper type of fire extinguishing agent.	
	5. Accurate reporting of type and severity of fire.	
	6. Area of protective gear and emergency breathing apparatus.	

TABLE 3. CRITICAL FACTORS AND SKILLS/KNOWLEDGE REQUIREMENTS (Continued)

Training Category	Critical Factors*	Skills/Knowledge*
	7. Determination of need to emergency ventilate.	
III. Flooding recognition, isolation, and reporting	(Completed as above for items III through VII)	
IV. Atmospheric contamination recognition, isolation, and reporting		
V. Propulsion casualty ship control effects		
VI. Electrical casualty recognition, isolation, and reporting		
VII. Ships systems monitoring and control		

*No direct correlation exists between numbers assigned to items in middle and right-hand columns.
(from Goodyear, 1966)

TABLE 4. VISUAL AND MOTION CUE REQUIREMENTS: INDIVIDUAL TACTICAL OPERATIONS

Crew Responsibility	Visual Cue Requirements	Motion Cue Requirements
A. Tactical Navigation		
1. Select route to target.	A.(1) Terrain features to include roads, rivers, streams, tree lines, coordinated with tactical navigation map and with simulator flight computations.	A. N/A
2. Establish required ground track.		
3. Identify landmarks and checkpoints.	(2) Terrain detail compatible with map detail	
4. Verify checkpoint location with fixing equipment.		
B. Surveillance & Target Acquisition		
1. Scan terrain for landmarks, enemy positions, targets, friendly positions.	B.(1) (2) See A, above.	B.(1) SGS
	(3) Identifiable target and landmarks, to permit detection, identification and evaluation.	(2) Cockpit motion not essential.
2. Acquire and identify significant targets, terrain and cultural features.	(4) Capability for examination of target areas at low altitude.	

TABLE 4. VISUAL AND MOTION CUE REQUIREMENTS:
INDIVIDUAL TACTICAL OPERATIONS (Continued)

Crew Responsibility	Visual Cue Requirements	Motion Cue Requirements
3. Designate targets to pilot/co-pilot/gunner.	(5) Target characteristics to include size, detail cues and cues to target activity (smoke, tracks, firing, glint, realistic deployment.	
4. Verify target positions with map.		
5. Evaluate significance of features identified on terrain.		
6. Make weapon-delivery decisions.		
C. Target Engagement		
1. Identify target.	C.(1) (2) See A, above.	C.(1) SGS
2. Identify friendly positions.	(3) (4) (5) See B, above.	(2) Pitch, roll to support timely and accurate control of attack path.
	(6) Tracers, weapon flares.	
3. Select appropriate weapon/weapon sequence.	(7) Weapon effects.	(3) Yaw in support of heading control and to provide distracting cues to gunner in SGS.
4. Establish pilot/co-pilot/gunner coordination procedure.		

TABLE 4. VISUAL AND MOTION CUE REQUIREMENTS: INDIVIDUAL TACTICAL OPERATIONS (Continued)

Crew Responsibility	Visual Cue Requirements	Motion Cue Requirements
5. Identify alternate attack modes.		
6. Evaluate alternate attack modes.		
7. Establish attack path.		NOTE: Motion cues in target engagement serve three basic purposes: (1) Provide immediate, obvious information to the pilot on aircraft attitude and flight path changes, permitting realistic attention-sharing between sighting and weapon delivery equipment and visual and instrument flight path data.
8. Establish attack angle.		
9. Select break point.		
10. Lay weapon(s) on target.		
11. Launch/track/monitor weapon.		
12. Assess target effect.		(2) Alert to co-pilot/gunner to pilot actions without requiring the co-pilot to directly monitor pilot activity.
13. Break from target.		
14. Re-enter attack path/ continue break.		(3) Provide realistic distractions, permitting the co-pilot/gunner to learn to operate in a realistic environment.
15. Maintain area surveillance throughout target engagement.		

TABLE 4. VISUAL AND MOTION CUE REQUIREMENTS: INDIVIDUAL TACTICAL OPERATIONS (Continued)

Crew Responsibility	Visual Cue Requirements	Motion Cue Requirements
D. Formation Flight		
1. Select rendezvous point.	D. (1) (2) See A, above.	D.(1) Pitch, roll, heave to permit timely and accurate control of aircraft position in formation.
2. Identify rendezvous point.	(3) Aircraft visual detail, in 3D.	
3. Establish visual contact with other lead aircraft.	(4) Visual parallax cues.	
4. Identify visual position references.		
5. Take up position, on command.		
6. Change formation:		
a) Identify visual position references.		
b) Take up position, on command.		
c) Maintain position.		

(Excerpt from crew training requirements analysis for AH56A helicopter, Link Group, HRB Singer Corp) which is based on Guilford's (1967) structure-of-intellect (SI) model (Figure 10). In SI theory, human intellective acts involve an operation, a content and a product. These three dimensions and their subgroupings permit 120 combinations (triads). What Siegel accomplished was to identify the specific tasks performed by the tactical coordinator, then fit these into the SI framework, and estimate task difficulty on a scale between 0 and 100. Specifically, the extent to which each of the 14 SI mental functions (5 operations, 3 contents and 6 products) is involved in each of the 50 tactical coordinator tasks was estimated on the 100 point scale.

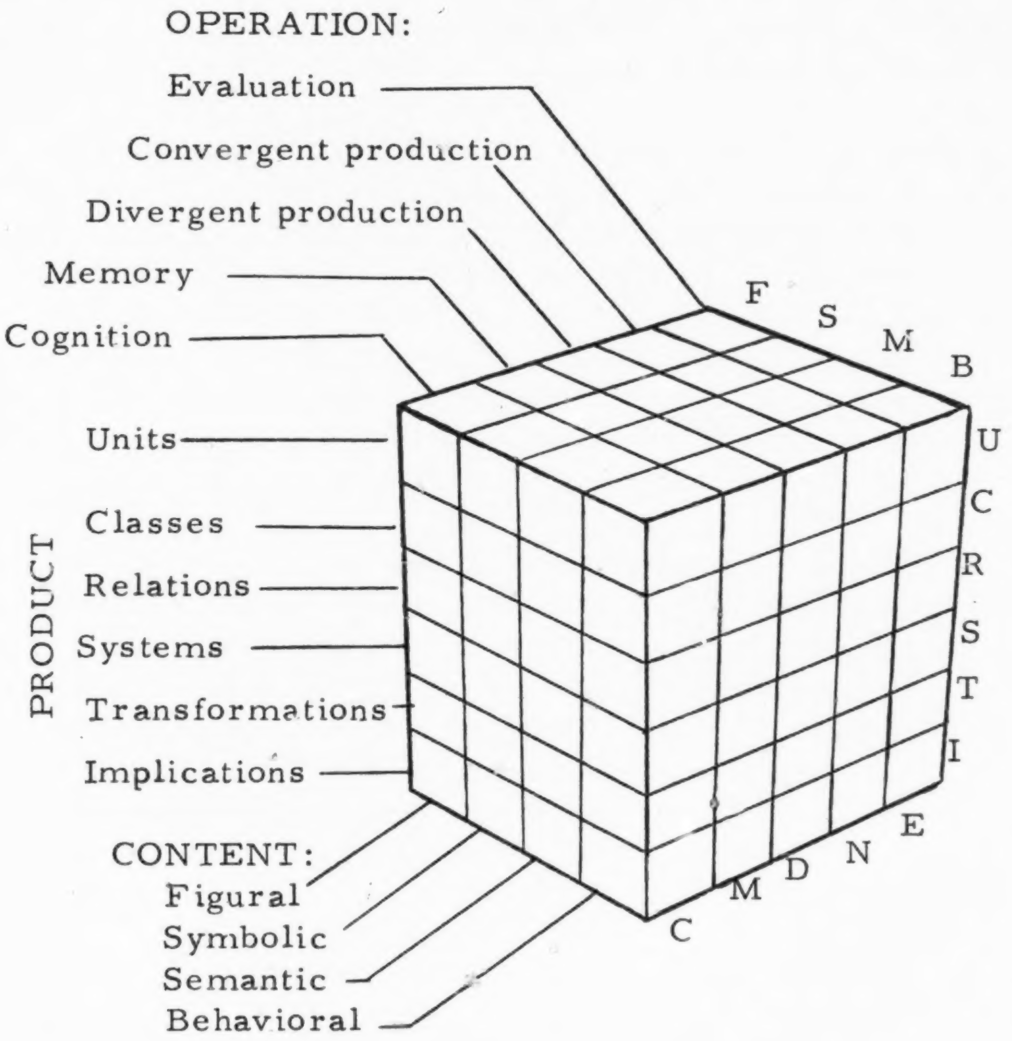
Schematically, the procedure is as follows:

develop job task list (interaction with subject matter experts) ⇨ fit the tasks into the SI model ⇨ Compute maximum involvement-by-taxation integrals (maximal intellectual triads)

From this analytic base of task information, judgments were made on the kinds of equipment capabilities needed for training in ASW tactical problems.

An intellectual load analysis (presented in Siegel and Federman, 1968) indicated two types of information: which aspects of the tactical coordinator job imposed the heaviest intellectual load (training requirements); and what specific kinds of intellectual activities were involved when the man was heavily loaded (training content). For this specific ASW system, computed maximum "involvement-by-taxation" integrals (maximal intellectual triads) indicated a principal requirement for training in interpretive, judgmental, problem-solving aspects of the man's job. The so-called executive functions of the tactical coordinator, the "thinking" aspects of his job (i.e., analyzing tactical information, determining pertinent information, planning courses of action, making decisions) fell out as the prime training requirement.

2.3.1.1.5 Interrelationship Graphing--Another, rather unique form of rational analysis is the Interrelationship Graph (IRG) technique, developed specifically for computer model development (Frye, 1965). It provides a topological representation of the structure of a simulation model which identifies all model elements and shows relationships between these elements. The IRG is a network-type diagram which is similar in definition to other forms of graphic analysis in that interconnected geometrical figures are used, but they represent numbers which represent quantities of interest. Considerable symbology is utilized in the IRG which cannot be efficiently described here, but the IRG rules are simple and easy to learn. They are explicated in Frye (1965). The primary purpose of the IRG is to


OPERATION:
Evaluation
Convergent production
Divergent production
Memory
Cognition
PRODUCT
Units
Classes
Relations
Systems
Transformations
Implications
CONTENT:
Figural
Symbolic
Semantic
Behavioral
F
S
M
B
U
C
R
S
T
I
E
N
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C

Figure 10. Guilford's Structure-of-Intellect Model (from Siegel and Federman, 1970)

serve as a communications tool for those working with digital computer simulation. The technique has not yet been fully developed and refinements in the method are needed as well as explorations into its use for other purposes. For example, it appears useful in quantitative analysis. Sensitivity analysis (perhaps on-line with a computer) appears as a promising application. The use of IRG's to define sequences of training which are to be automated (mission modeling) is of particular interest for the design and utilization of synthetic training systems.

2.3.1.2 Summary of Task Analysis Methods. Task analyses methods have the feature in common that all are rational approaches which attempt to categorize system performances for the purpose (i.e., our interest) of training system design. They are, at best, heuristic descriptions of activities at the functional interface of the man and that with which he interacts. Today, task analysis methods leave much to be desired for training system design. The methods continue to be cumbersome, ill-defined and non-standard, what Miller (1962) has called the "limping practices of the present."

Experience with task analysis has made clear the fact that its content is not generalizable across training situations--it is tailored to the needs of the system contemplated. Unfortunately, the process of determining the task requirements is complex and difficult and the available procedures are inexact and cannot be applied in any standard way. The process is subjective and the adequacy of the results is due in large part to the skill of the analyst. At present, the form and content of the information derived from task analysis is such that it is not readily translatable into design specifications.

2.3.1.2.1 Research Issues. A number of issues can be identified all of which can be gathered under a single purpose--developing the form and content of task information so that the output is directly useful in decisions on training device design.

An issue of some consequence is the definition of what is expected (and also not expected) in task information for device design decisions. This relates directly to the current problem of the inability to translate task information directly into design terms. Thus, an effort should be devoted to the development of criteria to determine what is of consequence in defining tasks to be trained. Refinements are needed beyond the current practice of considering tasks which are: important to system effectiveness; require high skill requirements; and will yield improved performance through training. We suspect that this development must occur around families or classes of training systems because of significant differences in task requirements, specifically among (1) OFT's involving motion and outside-visual world requirements; (2) tactical team trainers emphasizing tactical decision making; and (3) generalized trainers emphasizing major functions to be trained.

Detailed task classification data are also required but far in advance of the rudimentary task taxonomies currently on the scene. These data should be organized so that eventually common task factors pertinent to classes of training systems will become available to designers to be used in checklist or dictionary fashion, thus obviating the time, expense and effort required to analyze each new situation from the ground up. The data, once organized and available, preferably in a computerized data bank, would be pertinent to any device design situation and thus, would cut drastically the time for any new analytic effort.

Current behavioral taxonomies are of limited value in developing training objectives for a device. These have attempted, with limited success, to obtain a set of behavioral elements or categories which can be grouped into defined sets of distinct task categories so that patterns of task attributes can be prescribed for specific training situations. What is needed is a standard set of terms which can be used directly in describing operational activities.

Allied with the above is the need for a "short cut" task analysis technique or families of techniques which have the power needed for determining training requirements, but tailored to the needs of the system under study. This would be of considerable value in developing the functional requirements for any contemplated training system, for time constraints and the complexity of the systems quite often preclude the organization of task data to the level required for effective human factors design inputs.

2.3.2 *Training Objectives*. The effectiveness of the training system design, i.e., how the training environment is provided to facilitate the necessary learning, depends also on a clear understanding and expression of the objectives of the training to be accomplished. Explicit statements of training objectives are needed which define training content. A relevant, complete and well organized list of these training objectives serves as an important guide for decisions on what must be simulated (extent and precision of the simulation parameters). The desired form for specifying training objectives is well-documented. So far as their structure for training device design is concerned, a training objective must specify *what* is to be trained with a description of what the individual or the team must be able to accomplish at the end of training to satisfy the objective. Included is a statement of the *conditions* under which mastery of the objective is demonstrated, and where applicable, the *standard* of performance (minimum level acceptable) describing the attainment of the objective. Each objective is stated in terms of observable performance so as to permit the measurement of its attainment. Thus, for each objective, the following is required:

• Performance elements	These are achieved from the definition of task structure. The

	task analysis yields task statements (skill and knowledge requirements) which serve as the performance element (i.e., what is going to be trained).
• Measurability	Measuring and scoring of performance is tailored to the training objectives (see Phase 5B of this section).
• Conditions of performance	This specification is obtained from the analysis of the operational system (see Phase 2 of this section).

The development of training objectives is based on the task structure, with task statements serving as the performance element. Our interest is in terminal objectives, these define meaningful units of performance, relevant to real-world operations, which, when organized, describe the requirements for training. They serve as the framework for organizing the training system and for developing the system design. This component skills and knowledges the trainee must learn are anchored to these terminal objectives.

2.3.2.1 Sequence of Steps in Developing Training Objectives. The process of developing job relevant training objectives pertinent to device design decisions is outlined in the following progression:

Step 1: Describe and analyze the operational system--Pertinent information on the operational system is assembled which includes the description of the system and its components, the missions, the operational and tactical environment, and the primary mission profiles (accomplished during Phase 2).

Step 2: Define task structure--An inventory is made of the duties associated with each position and the tasks associated with each duty.

Step 3: Conduct task analyses--Formal task analyses are conducted to determine detailed task structures and to assess the importance and criticality of tasks for training, e.g., tasks that are important to system effectiveness, have high skill requirements, and will yield improved performance through training. No well developed guidelines can be given for defining the criteria to determine what to train. Most often the decision rules place most weight on judgments reflecting on the rationale given above and crude distinctions are made (e.g., a level of 1 may mean that the task should not be taught at all since it is not judged important to mission success, or can be easily acquired on the job; a level of 3 may mean that the task is important to mission success and is difficult to teach on the job, has high skill requirements, and so on) (see Section 2.3.1).

Step 4: Prepare detailed task descriptions--For those tasks that have been identified for the training system, detailed task descriptions are prepared. The goal of this effort is to determine the skills and the required knowledges involved in task performance. The result is an organization of tasks to be performed and the component skills and knowledges that are involved in each task. The task statement defines the performance elements in the expression of the training objective.

Step 5: Express the task statements in the form of training objectives--When the intended performance situation is defined, the meaningful units of performance are identified and selected and the necessary immediate learning needs are established. These should describe clearly what the trainee must do to satisfy the objective. As indicated earlier, the performance element of the objective is derived from the task structure (intended performance situation).

In addition, the conditions under which performance is to be attained form an important part of the objective since a number of factors influence the difficulty level of training as a function of task loading. The conditions to account for can be categorized as follows:

- physical environment--involved here are environmental effects such as visual, aural, motion, and earth atmosphere (sea conditions, conditions of flight, and underwater conditions).
- task loading--involved here are issues of performance complexity arising from increasing task demands and the tactical environment which define the amount of "problem clutter" in generating the

situation for training. The factors subsumed under tactical environment include: target configurations, speed of an engagement, communications requirements, friendly force composition and disposition, and enemy threat.

- mission complexity--task requirements are different depending on the type of mission to be accomplished or on that portion or segment of the mission of primary concern. For example, in Air Force combat/logistics flight missions, considerable differences in task sets are found in the primary delivery segment of the missions, which call for quite different training requirements (Smode, Post and Meyer, 1966; Smode, Hall and Meyer, 1966). Also, the geometry of a simulated engagement is of prime significance in defining the conditions underlying a training objective.
- target maneuvering--tactical situations vary significantly as a function of target activity (evading/attacking, maneuvering, such as altitude changes in aircraft or submarine movements above and beneath the layer) and the relative geometry between own-system and a target(s).
- non-normal operations--malfunctions and emergency situations require specification (as pertinent) in the training objective.

The final component in the training objective is the specification of the standard of performance (as pertinent) that must be met to indicate achievement of the objective. This may be in such terms as error tolerance, speed of accomplishment, or procedural accuracy.

Ammerman and Melching (1966) have reported their work on the development of training objectives (which is part of the systematic effort by HumRRO on the design of training systems). Although their work has centered more broadly on educational contexts and on training situations in Army Service Schools (curriculum development), the material is nevertheless of value for the design of synthetic training systems.[1]

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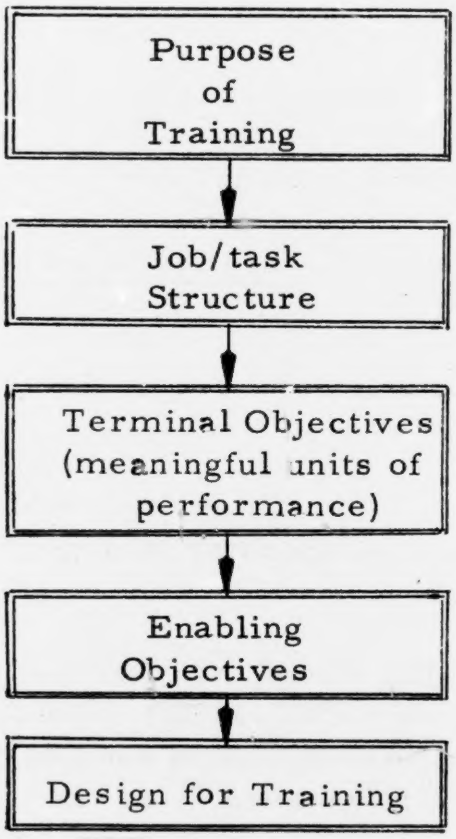
[1] For additional information, see Mager (1961), Tyler (1964), Smith (1964), and Rundquist (1967, 1970).

A distinction is made by these writers between terminal objectives and enabling objectives. Terminal objectives define meaningful units of performance that are relevant to real-world requirements and are critical for instruction. They denote final criterion performance and are valid representations of the instructional goals. Terminal objectives serve as the framework for organizing the training system and as the anchor for identifying the enabling skills and knowledges. They provide the base for developing the system design. Enabling objectives are not instructional goals per se but represent immediate learning demands for attaining the terminal objectives. These define what the trainee needs to learn and consist of the component knowledges and skills that must be mastered in order to achieve the terminal objectives. Thus, they bridge the gap between entry-level capability and end of instruction goals. Since they represent the learning difference between where the trainee is now and where he should be, they are derived from the knowledge of the trainee population characteristics and from the terminal objectives and they describe the means to attain the directly meaningful terminal objectives. The sequence of development in the design for training proceeds as follows:



Terminal objectives can vary in a number of ways and thus, their utility and communicability are influenced. Ammerman and Melching (1966) have classified terminal objectives in terms of five factors which account for their differences.

- Type of performance unit--the objective may refer to three types of meaningful units of performance. These are: specific tasks (e.g., performance gyro azimuth transmission check on a Nike Hercules radar); generalized skills (e.g., adjust the carburetor of any type of gasoline engine used on land vehicles); and generalized behaviors (e.g., maintain an awareness of safety hazards when working in a machine shop).

- Extent of action description--objectives may show considerable variation in the level of description. This may range from a statement of action only, to descriptions of representative or complete actions that are indications of the desired behavior.

- Relevancy of trainee action--this refers to the relatedness of the behavior of the trainee to that required in the job situation. Objectives tend to be highly relevant when they are derived from an analysis of the job situation (e.g., field strip a heavy machine gun).

- Completeness of structural components--statements of objectives are complete to the extent the components (action, condition, standard) are included.

- Precision of each structural component--this factor deals with the explicitness of each component in the objective.

2.3.2.2 A Sampling of Training Objectives. Several examples of training objectives are shown below.

Example 1: This is a simple example of a terminal training objective for individual operator task performance (Ammerman and Melching, 1966).

- The trainee, using rubber and friction tape, pliers (TL-13-A) and wire (WD-1/TT), should be able to make a standard field wire splice by completing each of the following steps in sequence.
  - From one conductor, cut off one plier's length (about six inches).
  - Mark each conductor six inches from end by inserting one conductor at a time into small hole of jaws of pliers.
  - Close pliers.

- Insert long conductor in small hole about two inches from end.

- Close jaws carefully, remove insulation.

- Repeat procedures for each conductor.

- Tie long conductor of one pair to short conductor of second pair, using a square knot.

- Etc.

Additional examples of training objectives for individual operator tasks are shown below (Ammerman and Melching, 1966; Rundquist, 1967).

- The trainee should be able to field strip the major components of an M-14 rifle under conditions of total darkness within five minutes.

- The trainee must detect errors in acquiring, processing, displaying and reporting of contact data during a programed exercise consisting of representative samples of audio-taped radar operator reports and corresponding pictorial radar presentations. Task: "monitors surface search radar operator in search for and detection of surface contacts, and processing, display and reporting of contact data." (Since in this instance, the performance to be taught with taped reports and pictures of radar scopes is different from the task on-the-job, the task itself is given for reference).

Example 2: Single Destroyer, Single Submarine Tracking and ASROC Attack (reference: Section IV, this report, ASW operations in device 14A2).

- Conduct basic ASROC attacks; achieve three complete fire control solutions and demonstrate weapon launch procedural accuracy in all subteam performances. Team must satisfactorily complete fire control solution and ASROC (Mk 46/1) launch procedures in attacking a maneuvering submarine at various ranges and courses relative to own-ship. Secondary emphasis is placed on accuracy and speed of performance.

Example 3: SH-3 Helicopter 46/1 Torpedo VECTAC from Sector Screen (reference: Section IV this report, ASW operations in device 14A2).

- Implement a coordinated search and attack on a conventional submarine attacking the screen. Positive control of the helicopter will be effected and the following accomplished:

  - Headwind vectoring procedures while positioning Helo in search sector.

  - Positioning the Helo in square search pattern of operation PUMPKIN (51S) using crosswind vectoring technique.

  - Implementing an urgent SH-3 46/1 VECTAC.

  Full reporting procedures over RT Nets using the scramble Table will be accomplished.

Example 4: Training objectives developed for a Submarine Casualty Control Trainer (Goodyear, 1966).

Seven functional training units (i.e., closely related and integrated subject matter areas for training) were identified.

1. Ship Command and Control
2. Fire recognition/isolation/reporting
3. Flooding recognition/isolation/reporting
4. Atmospheric contamination recognition/isolation/reporting
5. Propulsion casualties ship control effects
6. Electrical casualty recognition/isolation/reporting
7. Ship-systems monitoring and control.

Within each of these 7 functional training units, a series of training objectives were prepared. The example given is for only one, the Command and Control Casualty training unit. The following instructional aims were defined.

- Ensure a high degree of tracking capability by planesmen so that cues of a malfunction for indicators, control system or ship feel are not confounded with erratic planes or depth control (high fidelity control capability).

- Develop in planesmen proper scanning habits among indicators (physical representation of diving panel and BCP display arrangements identical to the class of ship).

- Develop discriminating responses to specific cues of normal/abnormal performance (depth, speed, and cross-coupling effects on ship accelerations in the X-Z plane should be highly similar to the effects of plane and flooding casualties and casualty recovery actions).

- Develop ability to shift to alternate modes of operation, such as rate control, manual overrides for emergency blow or plane control and local manual control of planes, rudders and vents (high fidelity simulation).

- Ability to analyze and maintain trim control so that cues of a malfunction from indicators, control system, or ship feel are not confounded with a heavy condition, down angle, up angle, or list due to improper trim (high fidelity trim analysis and control).

- Ability to recognize, diagnose and correct for depth and depth-rate control problems due to indications of stern plane, fairwater planes, or rudder casualties.

- Ability to initiate ship control actions in response to general emergencies and alarms. This includes emergency surfacing, depth change for emergency ventilation and depth change to ordered depth.

- Develop in the team the skills in evaluating the progressive effects of recovery action and performance of follow-up action necessary to restore a safe operating envelope. (High fidelity ship performance and ship systems response; should be equipped to reveal depth excursion, air-bank management, including negative recoverability effects.)

- Exercise the ship-control team in communications and team interactions. Emphasis is placed on coordinating control of depth and trim angle.

2.3.2.3 Organizing the Training Objectives. Since a number of training objectives will be identified for any given training system it is necessary to organize them so that the full range of device capabilities needed can be identified. The objectives are usually graded in difficulty in terms of the factors identified above, vis-a-vis the task content. This grouping can be accomplished via two dimensions.

The first is the procedural to the fully integrated (or tactical) dimension whereby the early or initial objectives are concerned with procedural adequacy, e.g., the ability to operate basic equipments, knowledge of the activity sequences, plotting, communicating, etc. From this are built up more complex objectives (in which the former are included in that they represent building blocks for more complex activities). Thus, a later set of objectives would emphasize full utilization of those portions of the system to be simulated, such as, the tactical employment of a system against an enemy (e.g., general purpose training in tactical ECM, involving defensive ECCM, Jamming, Radar Homing and Warning, and Reconnaissance and ELINT, such as provided by device 15E18).

A second dimension specific to team trainers is the organization of objectives at individual/subteam levels and progressing to team sequences involving the range of complexities occurring in real-world operations. A good example of this is provided in Section IV for ASW operations in device 14A2. Three groupings of objectives were developed to provide a series of training exercises graduated in difficulty. The first block centered on basic attack procedures (non-mission context) in which the objectives specified the development of fire control solutions and launch procedures for the relevant weapons. The next block of objectives was devoted to single ship sequences in the screen mission context where the previous block requirements were imbedded in a total mission from search and detection through weapon assignment and target prosecution. The final block dealt with multi-unit missions (Search and Attack Unit (SAU) context) involving more complex tasks of coordinating the operations of other units. This represents the fullest expression of coordinated team training objectives. Thus, a graduated series of training exercises are developed and the strategy for training is based on an interrelated series of specific training objectives.

2.3.2.4 Summary of Research on Training Objectives. Simply speaking, the training objective is a precise means of communicating instructional goals. It is in a form most useful for device design when it is stated explicitly in terms of performances expected of trainees at the end of instruction, rather than in terms of training content or subject matter.

The present development of the training objective has emerged from the confluence of work in education (see Tyler, 1964), the work in programed instruction (see Mager, 1961) and the sizeable effort in human factors and training research on the development of rational analysis techniques for describing task structure in complex man-machine systems. While significant and meaningful development of training objectives has been accomplished in the decade of the 1960's, the question of meaning is this: have behaviorally stated objectives had a significant impact on the design of instructional systems? Melching (Melching, et al, 1966) also articulates several key issues: are objectives prepared on the same system comparable among writers? have existing statements of objectives satisfied the criteria of, the performance element, the conditions under which competence is demonstrated, and the standard of performance? Has the nature of the behavior of the trainee been clearly communicated?

The answers are most clearly, no. Training objectives that have been published exhibit no standard pattern. They vary considerably in explicitness and detail, in the relationship they bear with the performance situation and in the type of training system involved. Most statements of objectives fail to include the important conditions and the standards of performance relevant to the training action.

Ammerman (in Melching, et al, 1966), has identified several major sources of variation in statements of training objectives. The first is in the level of specificity with which the trainee action is stated. As mentioned earlier, the terminal objective is associated with meaningful units of performance and it establishes the criterion performance that is to be attained in the training system. The enabling objectives to be meaningful (i.e., achieve organization), are anchored to the terminal objectives. It is the specificity of the enabling objectives that is cause for questioning their usefulness (i.e., each consisting of one component action or knowledge to be learned to attain the terminal objective).

The second source of variation is the extent to which the action is described. Most examples do not contain any descriptions beyond stating the action and are quite nebulous. Extensive descriptions of trainee actions are required to provide the necessary communicative power. For example, the additional description might be a listing of sequential steps for a procedural task, or a listing of observable actions which if exhibited would be evidence for attainment of the terminal objective.

A third source of variation is the completeness of the statement of the objective. This refers to the completeness of the components of a training objective (i.e., action, conditions, standard). The major neglect is in the depiction of the conditions of performance and the standards of performance.

A fourth source of variation is the relevance of the performance stated in the objective. This is the validity requirement which too often is not met, presumably due to a lack of knowledge about the exact job performance requirements.

Confusion in stating training objectives has resulted from an inability to distinguish between terminal and enabling objectives (Ammerman and Melching, 1966). Terminal objectives represent end-of-training capabilities sought by the instructional system and they are determined by relevance to the operational situation represented in training. Enabling objectives are the necessary training tasks that bridge the gap between entry-level trainee capability and the desired outcome as defined by the terminal objective. Thus, enabling objectives depend on terminal objectives for their value; both are essential to meaningful training design.

2.3.2.5 Research Issues. The importance of performance-oriented training objectives is well understood in training requirements analyses. Two issues are prominent for research. The first concerns the value and impact of training objectives for training device design. The major emphasis on performance objectives to date has been in curriculum design and test construction. So far as synthetic training systems are concerned, their greatest impact is felt during device utilization rather than in the design process. Once the device is on-line, training objectives are central in developing an organized training program for device utilization based on a series of training exercises graduated in complexity and difficulty. What is needed is research to define procedures for incorporating training objectives in the process of human factors design of synthetic training systems.

Aligned with the above is the research need to standardize the component structure of training objectives for use in device design, especially for classes of training devices having similar components (sensor systems, weapons systems, etc.). Since enabling objectives represent task events and sequences, this should tie in meaningfully with research on task commonalities. The work on task taxonomies relating task structure to instructional methods is relevant here.

2.3.3 Definition of Simulation Elements. The reason for the operational job analysis is to achieve an idea of task structure, which includes, a description of the trainable critical tasks and an integration of these tasks by positions. The range of these task requirements to be achieved by training provide the clues for determining what is to be simulated, and it is the "what to simulate" (i.e., extent of simulation in the trainee compartment(s) in functional terms) that is an important human factors contribution to device design.

Thus, we are ready to begin a key effort, that of defining the environment in which learning will take place, i.e., specifying the extent of simulation required via the design options selected. The range of task requirements provides the clues for the numbers and types of parameters needed in simulation. The identification of simulation elements, i.e., those factors to be simulated that determine the representativeness and complexity of the tasks which are defined for training, and the parameter values (range, envelope, number) are the crucial human factors inputs to the definition of fidelity of simulation in the trainee compartment. These simulation elements must be clearly specified in order to achieve the required device configuration to enable training to the level expected (training objectives), and also to have a flexibility for handling additional training objectives should they emerge after on-line experience with the device.

The basic human factors effort is to identify the simulation elements to be represented for training, for these define the device hardware and the software programing requirements. At stake are the following:

how much to simulate (tasks to be trained), and what levels of fidelity to provide (with the implicit cost-effective question of, what can be omitted from complete fidelity of representation without significant decrease in training value?). The simulation engineer needs to know how much of a task to represent, namely, what and how many parameters must be simulated to represent the task.

Thus, the classes of simulation elements that must be provided in the training environment (trainee compartment) to achieve the defined and the anticipated training objectives are identified at this time. These classes of elements refer to: own vehicle units; targets; and media. The matrix shown in Figure 11 is helpful in identifying the categories of factors relevant to the system under consideration. The values of the simulation elements (number, range, envelope) are specified in some detail subsequently in Phase 5, which is devoted to defining the characteristics of the operational environment to simulate for training.

In the present phase, attention is also devoted to outlining a useable measurement system to provide measures and scores for evaluating the achievement of the training objectives. This effort is completed subsequently in Phase 5B concerned with the management of training at the instructor station.

2.3.4 Output. The completion of this phase yields the identification of what training is needed, vis-a-vis transfer of training. Task structure is put into perspective wherein task statements are listed depicting the activities performed by duty positions, together with the skill and knowledge requirements. Training objectives and the measurement requirements for assessing training effectiveness are also determined. Again, it is emphasized that the reason for this analysis is to provide a basis for determining the extent of the simulation required in the trainee compartment(s), culminating in the identification of the relevant simulation elements, to be included in the design of the system under consideration.

The activities completed thus far, now enable the gross definition of the training system (i.e., initial correlation between that piece of the operational environment to be simulated and the operational system in its present form).

2.4 PHASE 4: GROSS DEVICE DEFINITION. The definition of the boundaries of the training system can now be accomplished. This is the gross hardware orientation, centering on the trainee compartment requirements and represents the correlation between that piece of the operational universe to be simulated to meet the user's needs, and the operational system as it is or will be organized and employed.

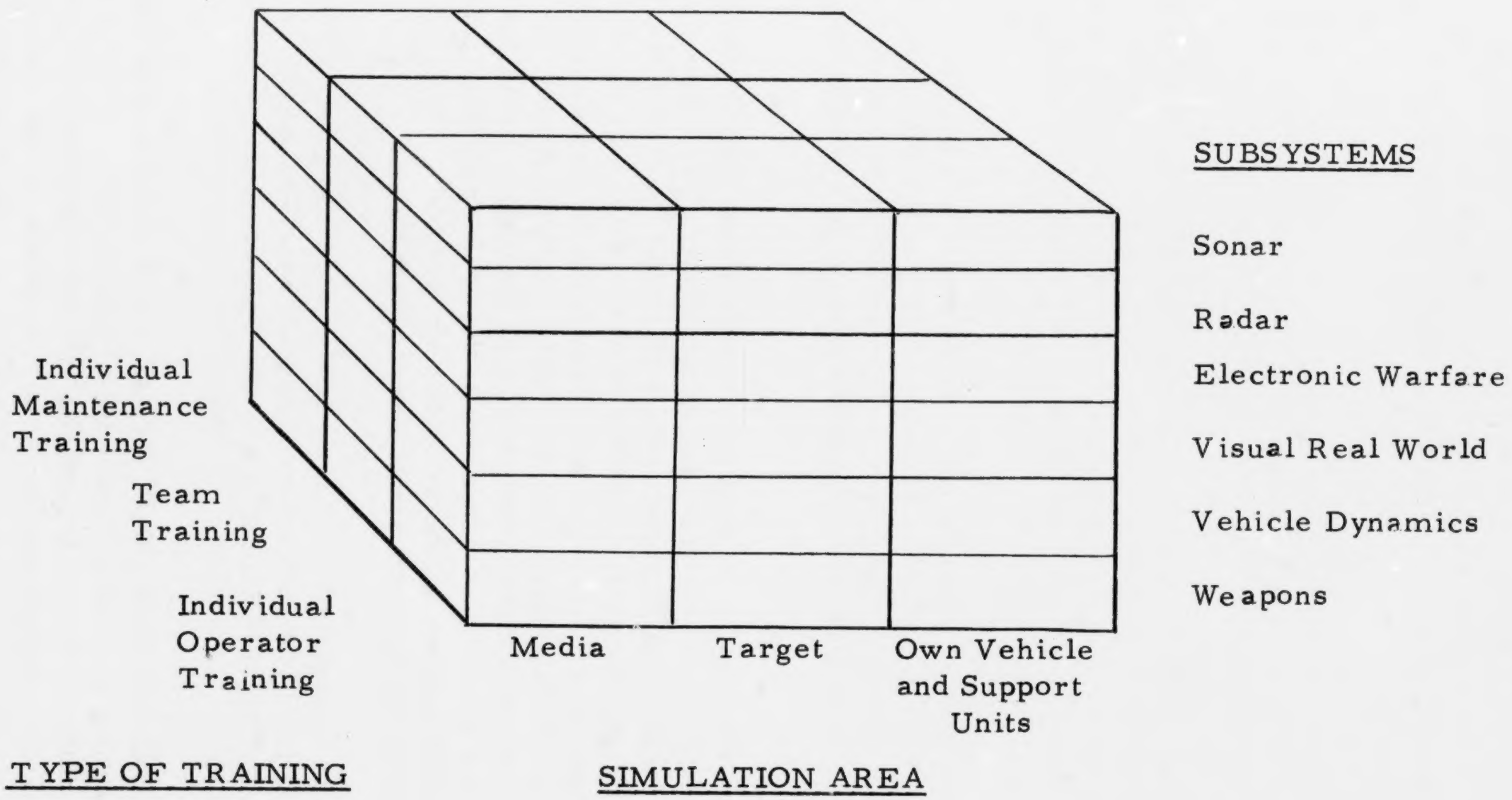

SUBSYSTEMS
Sonar
Radar
Electronic Warfare
Visual Real World
Vehicle Dynamics
Weapons
Individual Maintenance Training
Team Training
Individual Operator Training
TYPE OF TRAINING
Media
Target
Own Vehicle and Support Units
SIMULATION AREA

Figure 11. Simulation Elements Matrix

The following design features are accounted for:

- Overall device layout--The key dimensions of the training device layout are organized. Included are the equipment/console requirements for the trainee compartment(s), the instructor station area(s), briefing and critique area(s), computer complex (unattended) and administrative spaces. This may require additional inputs from the using agency depending on whether or not a fixed floor plan area is specified (availability of an existing building or space vs. new construction). Human engineering design principles are accounted for, in part based on published military standards and related documents (layout of work stations, traffic flow, lighting, environmental control, etc.).
- Arrangement of trainee compartments (as pertinent).
- Equipment summary--Quantity and types of equipments that must be represented in the device. This includes decisions on specific system suites, specific operational equipments (controls/displays), or generalized equipments (for providing training functions in devices not representing a specific operational system).
- Number of operational units to depict (number and type of own forces, number and type of enemy units/targets.
- Size of the tactical area of operations involved in the training.
- Complexity of the training anticipated (range of operational exercises/scenarios to be accomplished; procedural and tactical employment involving multi-unit operations; generalized training in major operating modes).
- Characteristics of the trainee population (number and types of trainees to be trained, entry-level requirements).
- Requirements for the scheduling of training.

2.4.1 Output. Overall device layout and the equipment complexes for training and the layout of the workspaces for integrated personnel operations (as applicable) are specified. The training system in its gross specifications is firmed up at this point, and from here, the detailed characteristics of the operational environment to be simulated for training are developed.

As mentioned earlier, the process of defining the device characteristics is iterative, beginning with the gross outline of the training system and continuing in refinement and modification as additional technical and administrative inputs are organized until the functional description of the training system is completed.

2.5 TRAINING DEVICE COSTS VS. TRAINING VALUE. The specification of design for a training system under development must take into account the issue of costs vs. training benefits. Tradeoff analyses are required to put into perspective the training value or advantage in operational capability afforded by a design alternative per dollar spent. This is a difficult thing to do, and at present there are no useful methods available for this determination that most people can agree upon. Most often, these decisions are made intuitively based on previous experiences, rarely have they ever been "just right," and the tendency has been to be generous in engineering features just to make sure that the user has what he believes he needs to accomplish training. Often, over-design is the result, with no clear correlate in heightened training returns.

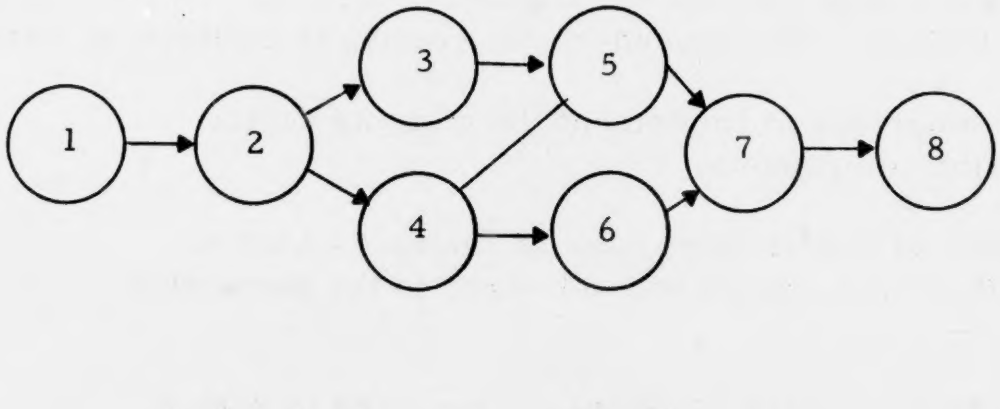
Cost tradeoffs may be influenced substantially by constraints having no technical basis. Foremost among these are features such as, a limited dollar budget available which forces an undesirable austerity on design; and requirements for simulating certain "demanded" operational characteristics which unfortunately contribute minimally to training.

The cost/effectiveness determination is a difficult undertaking since it is not a straightforward requirement but involves several sets of variables that must be taken into account by the human factors specialist. On purely technical grounds (which is rarely the case) the issue is one of the extent of simulation and the amount of fidelity of simulation to achieve certain training capabilities. The definition of the purpose of the training device figures prominently in tradeoff decisions. Purpose provides various "shadings" to what is meant by training value, and a number of issues necessarily come into play. Foremost are the following: the transfer of training situation (i.e., one-to-one correspondence with specific equipment suites vs. generalized equipments); the type of training system and the skill requirements; the levels of training anticipated; and the input population of trainees.

One feature should be made clear: strict adherence to a costs schedule may violate a design principle: that of providing a design which will allow the widest range of training to be employed consistent with training purpose. Obviously, at this stage, the design team is not clairvoyant in all that should be represented for training. The need for flexibility in design to maximize the positive transfer of training to the operational world, however, is well understood. Thus, one must be wary of extreme cost consciousness for often, the purchase of additional simulator capability may provide added flexibility in employing the device for training, which in the long run may better account for things unforeseen during the design stage, hence, yield a lower total cost in terms of minimizing required modifications to the device once it is in the field and operating.

Research has been unable to produce systematic techniques for defining training value achievable in training devices vis-a-vis dollars expended for hardware and software. No body of information (data, techniques) is available which provides the necessary guidance for achieving tradeoffs between cost of equipment and training value so far as selecting/omitting equipment which will govern the extent of the training capability (i.e., range or number of tasks to be trained). Data, however, are available for determining ways of representing tasks so that a satisfactory level of transfer of training can be achieved but with reductions in costs. This refers both to backing off from complete (high) fidelity of representation and to deliberate departures from reality to achieve training goals. These issues are explored throughout Section III of this report.

To be sure, sophisticated ways of cost/effectiveness accounting for optimizing training system design have been attempted. One attempt to formalize this accounting was a Naval Training Device Center program which applied systems analysis techniques to the determination of training equipment requirements. A procedure was developed for the ranking of tasks within a system in terms of the payoff of task training (as reflected in improved system operations) per training equipment dollar expended (van Albert, Jeantheau, Gorby and Parrish, 1964(a), 1964(b)). This, called the Training Analysis Procedure, was tailored to fit as a step in NTDC's training requirements determination process (called the Training Situation Analysis) which culminates in a Military Characteristics (MC) Document for the training device under consideration. The procedure begins with a system description and an identification of the tasks to be performed in the system. A premise of the procedure is that all identified tasks in the system contribute to system output; those that do not are not considered for training. The system operation is diagramed as a network. The example shown below shows a fixed sequence system where the events are numbered sequentially and tasks are referred to by the event numbers they link.



The second step is to collect performance data and estimate performance for each task before and after training (via interviews, observation and published data). Estimates are obtained for each task in the system with respect to the probability that the function will be performed successfully and also for the rate of performance. This is followed (step 3) by a specification (accomplished in conjunction with engineers) of the equipment required for training each task and the cost required to provide that training. From this, step 4 is accomplished, wherein cost-effectiveness ratios are computed for each task in the system in order to determine benefit to system performance of training each task in the system and to determine the relative payoff in benefit per dollar for training each task. The effectiveness (benefit) portion of this expression is the figure of merit (FOM), which is the percent estimated system improvement with training on that task.

For each task, a ratio is obtained defining: $\dfrac{\text{FOM}}{\text{Cost of achieving the improvement}}$,

These computations are carried out on an iterative basis. The task with the highest FOM/Cost ratio (i.e., greatest benefit per dollar) is considered "trained" on succeeding iterations. The iterations proceed until all tasks in the system have been "selected" in order of their individual benefit to system performance with training. The outcome of this procedure is a ranking of tasks in order of their benefit to system performance per dollar of equipment cost. Results are plotted as a step function, relating FOM to Cost on a task-by-task basis. The plot is a graphic representation of where to put the emphasis in the trainer.

An interesting point in the above technique is the determination of total costs of equipment per task. A system was selected on which the training analysis procedure was applied. This was the Marine Tactical Data System (MTDS), and a cost pricing was accomplished (Bertin, 1965). The engineer who accomplished the pricing did it within the usual costing framework employed by NTDC. The difference was that the cost estimates were made on each task whereas the normal procedure costs are computed on the overall trainer. The procedure for costing is outlined as follows:

- Block diagrams to implement the training device by major components.
- Schedule of events from time of contract award to time item is accepted and delivered to the particular site.
- Types and numbers of engineers required to design, develop and fabricate the hardware components.

- Development of work chart for calculating costs of:
  - engineering labor
  - manufacturing
  - material
  - overhead and profit

2.5.1. Research Issues. It is obvious that little in the way of formal approaches exist for cost/training value determinations. Engineering costing today accounts crudely for training value, i.e., only in terms of training system completeness. Thus, differences in cost reflect in the capability for training in terms of fidelity (for example, omission of classification cues in sonar operations; omission of IFF fade in MTDS), or control of training (for example, omission of automatic performance evaluation).

The Training Analysis Procedure, outlined earlier, has enough limitations to obviate its general use. It is limited to systems having definable quantitative outputs. Its task definition is not satisfactory in terms of consistency in identifying activities comprising a task and in accounting for task difficulty levels; and it is too crude in computation to account for the complexities of task behaviors that are modified during the course of training. At best, it is what the authors suggest--an initial attempt to remove some of the intuition from the results of training requirements analysis.

What is needed urgently are formal approaches for determining in standard ways, training value received for equipment costs expended. These should perhaps be based on operations research methods and data and expressed in mathematical models. Allocation and utility theory should be examined for relevance.

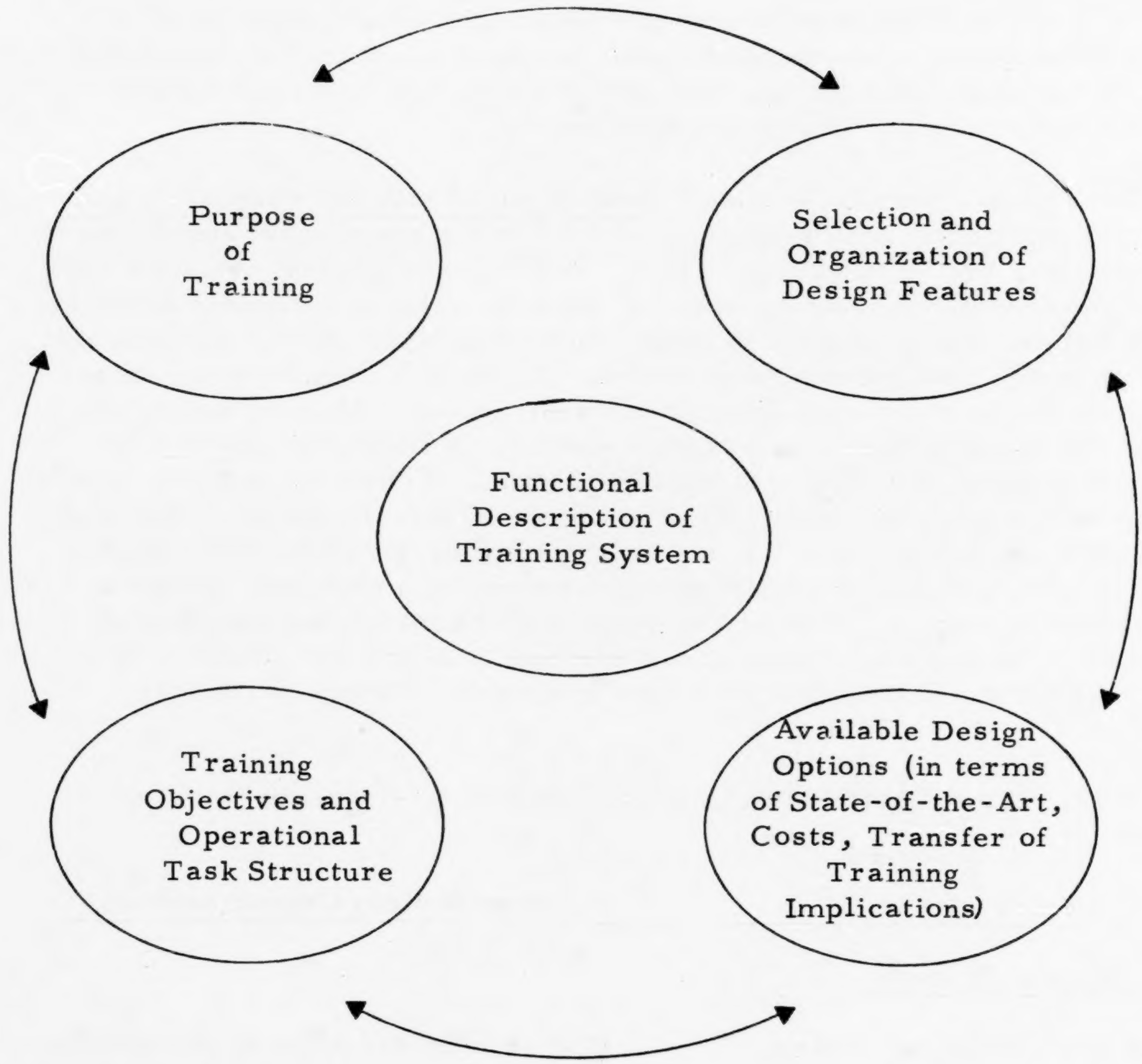
2.6 PHASE 5: CHARACTERISTICS OF THE OPERATIONAL ENVIRONMENT TO SIMULATE FOR TRAINING. The analyses thus far have provided the basis for defining that portion of the operational system to be simulated and organized as a training system. A number of key decisions have now been made:

- Purpose of training articulated and the basic fidelity of simulation requirements described.
- Training objectives identified and organized.
- Task structure defined and organized.
- Equipment complexes identified and the fixed components set forth.
- Overall training system and operational modes roughed out.

The human factors effort now concentrates on selecting the design alternatives which will define the manner in which the synthetic environment for training will be provided and how the shaping of learning (structure and control of training) will be accomplished. The human factors contribution to design embraces two distinct phases: 1) the fidelity of simulation issues in representing the operational environment in the trainee compartment(s), and 2) the management of training which concerns the monitoring, evaluation and control of training at the instructor station.

This much should be made clear at the outset: translating behavioral information into device design is not a straightforward operation. It is difficult for several reasons. 1) The state-of-the-art in training technology has not advanced to the position where transfer of training relationships are sufficiently understood, nor does a body of "training value" data exist that correlates well with design alternatives. 2) Synthetic representation (i.e., engineering capability) is not easily or completely achievable in every case. Compromises and less than desirable representation are used as the "best available" in certain areas. 3) Since 100% fidelity is not always possible (nor in some instances, desired), the extent of backing off from this and not sacrificing training value in both operational and motivational terms is crucial to effective human factors design. 4) There are alternative ways to "encourage" trainees to accept simulation as highly faithful to the operational world. Different tradeoff values are involved with each and the available design options must be identified and assessed carefully. 5) The values of deliberate departures from realism (deviations in configuration/operation from the operational system being simulated) to enhance training effectiveness must be clearly understood and effectively implemented.

To most effectively achieve the simulation requirements and fidelity levels, it is a desirable habit to view the design implications (hardware orientation) in terms of the training requirements. Decisions on what must be simulated and the selection of design alternatives depend substantially on the purpose of training, the training objectives, the task structure and the simulation options available within cost and state-of-the-art constraints. An interrelated revolving set of relationships is at work in which each increment in the functional design of the training system is related back to the training requirements information. The relationships look something like the following:


Purpose of Training
Selection and Organization of Design Features
Functional Description of Training System
Training Objectives and Operational Task Structure
Available Design Options (in terms of State-of-the-Art, Costs, Transfer of Training Implications)

The importance of this cycle is mirrored in the kinds of questions that come up constantly, such as:

- Is a periscope needed in the attack teacher?
- Is landmass simulation required?
- Should a terrain model (3-dimensional) or a film strip (2-dimensional) be specified for an air-to-ground missile control situation?

Answers to these kinds of questions are meaningful only in light of what training is supposed to accomplish, what people are involved and what they will do in training, what the job-task structure is, and how training will vary as a function of the design alternatives.

The design criterion is clear: provide the means for exercising and developing the human performances required in the operational environment. How to achieve this is not always clear. A system of general principles for the design of synthetic training systems does not exist in sufficient detail to provide the necessary support to human factors design. Nor is an invariant series of design principles always useful. There is a considerable number of different kinds of training devices currently in use. Most of these, especially the complex synthetic systems are built in limited numbers. In fact, it is meaningful to say that each important and complex training system is a research and development effort in its own right. However, most training systems can be grouped into a small number of device classes, each class possessing characteristics common among its members. Within a class, there is a series of design principles that hold for any member of that class. The approach taken in this method is to provide guidance by organizing and developing design issues common to classes of training devices.

Three major classes of devices are identified, vis-a-vis training purpose:

Device Class	Primary System Characteristics
Tactical Systems	
(Complex multi-man airborne, surface and sub-surface trainers emphasizing tactical team training)	Own vehicle and support units characteristics Target characteristics Multiple sensor classes and displays Vehicle position geometry Environmental characteristics Weapons characteristics
Operational Aircraft Systems	
(Fixed wing and rotary wing Operational Flight Trainers and Air Weapon System Trainers)	Real-world visual simulation Instrument displays Vehicle motion Sensor displays Vehicle dynamics Weapons characteristics

Device Class	Primary System Characteristics
Individual Operator Trainers	
(Specific part-task training devices, generalized/universal training devices)	Procedural events fidelity Instrument/sensor displays Weapons control characteristics Target characteristics

Many issues must be considered in arriving at a description of the training system under development. Some obviously are peculiar to a system and are generally a one-shot solution to the problem at hand; a number of others, however, are more basic and are involved in the development of most training systems or in the development of a class of training system. These latter issues, the numbers of recurring and fundamental design problems in the development of most synthetic trainers, are of prime interest to this guide and receive priority emphasis.

To place the key design issues in perspective, the human factors inputs in the specification of functional design are subsumed under two major and interrelated categories:

- Representing the operational environment in the trainee compartment(s).
- Providing for the management of training--structuring, monitoring, evaluating and controlling training at the instructor station.

Achieving the design options available in specifying the functional characteristics for the training system requires that a number of questions be formulated, phrased so as to consider the relationship with training purpose and task structure. These design issues will form the basis for the presentation here. What the human factors specialist must consider is documented here and ranges from relatively simple concerns about items that must not be overlooked in the design process, to complex design issues involving a design choice based on reasonable alternatives. The issues underlying each design question and the design alternatives or options for solution will be identified. In Section III, specific and quantitative information from the research literature is presented in support of these issues. In addition, research needs are defined for those instances where human factors design data are incomplete or not available.

2.7 PHASE 5A: REPRESENTING THE OPERATIONAL ENVIRONMENT IN THE TRAINEE STATION(S). So far as organizing the environment in which the learning will take place is concerned, the central issue is, fidelity of simulation. For human factors, fidelity has meaning in terms of the training process and the realism necessary to promote transfer of training. Defining the design characteristics for maximizing transfer of training from the synthetic environment to the operational requirement revolves essentially about two interrelated questions: what/how much should be simulated? and how well should this be represented?

Trainee compartment design considers most prominently the issues involved in achieving simulation fidelity, that is, specifying the hardware (displays/controls) involved in the device and the fidelity levels required at the man-machine interfaces, ranging from high fidelity in engineering simulation to deliberate departures from reality involving special features of design not found in the operational system, in order to enhance learning.

To place trainee compartment design in perspective, the range of human factors issues and design alternatives are subsumed under two major categories:

- Configuration of the synthetic system.
- Simulation elements and fidelity of simulation.

The issues discussed are not necessarily of similar importance in terms of training value or of the human factors effort required, nor is there a recurring similarity in the way each issue is handled and resolved. As indicated earlier, the approach calls attention to the range of human factors issues involved in trainee compartment design and this provides the reader guidance in selecting those topics pertinent to his specific needs.

2.7.1 Synthetic System Configuration. The job at this point is to flesh-out the system components involved in the trainee compartment. The need for specific simulation capabilities is now explored based on the groundwork laid in the previous phases. To be resolved, are those portions of the subsystems that must be represented that significantly affect training capability. In many devices, particularly multi-man tactical trainers, direct transfer of training is desired from device to the operational vehicle, hence, replicas of consoles and equipments are desired in the compartments. Similarly, OFT/WST's rely on high fidelity cockpit mockups. Certain generalized trainers provide training across a range of specific systems (e.g., device 15E18, or the Air Force Simulator for Electronic Warfare (SEWT), but nevertheless require high fidelity in the specific EW equipments so that the signal signatures achieved are equivalent to those in the operational environment so far as the trainee is concerned. Thus, decisions are made on the "core" equipments needed to operate analogous to the real world. What instruments/equipments are operable replicas, what are operable non-replicas and what are non-operable replicas depend on training purpose.

The fleshing-out (i.e., defining what is to be simulated) of the configuration considers the following:

- Appearance and operation of key equipment complexes (controls and displays) in trainee compartments for pertinent subsystems.
    - Compartment/cockpit configuration
    - Real-world visual
    - Platform motion
    - Sensors
    - Weapons
    - Specific capabilities, vis-a-vis training purpose (e.g., inflight refueling)
- Exact representation of operational equipment (fixed components central to system operation) for those portions of the system to be simulated (e.g., communications/navigation facilities such as radio, TACAN, Doppler Radar Navigation; relevant vehicle instruments; periscope configuration, etc.).
- Functional representation of fixed components to provide information inputs on discrete events, where these equipments are related to the real system only in an output or function performed, but not in appearance or operation.
- Extra mission equipments (e.g., for demonstration, for trainee selection of an exercise, etc.).

In tactical team trainers where the training emphasis is on coordinated team procedures and the tactical employment of friendly vehicles (own-ship and support units), the design practice is to provide replicas of equipments and consoles in the compartments (i.e., duplication in appearance and operation of key equipment complexes and exact representation of communications equipments and ancillary displays and controls such as ship's instruments). This is logically sound in that direct transfer of training is desired since these devices are used in direct support of line vessels. Team practice in the device should be highly realistic of actual shipboard operations with system suites equivalent to those found aboard ship, and in similar configurations.

Design practices for operational flight trainers rely on high fidelity cockpit mockups. Decisions on operable instruments and equipments are based on defined normal operating sequences and emergencies to be trained. The selection of active instruments should be agreed upon with the using agency for the device. The selection of operational components, however, must take into account future modification possibilities and training flexibility.

Thus, for devices representing an operational system, a listing of all equipments pertinent to the compartment is made; for generalized/

universal trainers, a listing of all functions to be performed is made and the simulation elements then determined to achieve these functions.

The employment of actual system equipments (e.g., Government FurnishedEquipment) vs. simulated equipments is resolved here, but for the most part, this is an engineering issue which considers the availability of operational equipment, maintenance (ruggedness/cost) and budget/cost factors. The human factors input is in the analysis of possible discrepancies in fidelity when using simulated equipments, and in deliberate modifications in the information displayed on operational equipment to enhance training effectiveness.

2.7.2 Simulation Elements. Once the configuration of the device is set, the issues of specifying those parameters which define "how well" simulation is achieved, are resolved. Specifying the fidelity of simulation is the crucial requirement in representing the synthetic environment in which training is conducted. The human factors input concerns the definition of the simulation elements. These represent, in hardware terms, the parameters and their values (range, envelope, number) needed to accomplish the desired training, hence govern the range and complexity of task installation in the device. The simulation elements which are controllable (manipulated or modified manually or automatically via the instructor station) determine the perceptual equivalence of the training environment and the operational situation. The ability to provide the desired training in the identified tasks is directly dependent on the availability and adequacy of these simulation elements in a training device (i.e., which ones are selected and how usefully they are represented). Shortcomings in the simulation of these elements define the shortcomings in the training capability of a device (i.e., simulation elements are associated with the representativeness/complexity of the tasks to be trained in the device). The proverb, "for the want of a nail, a shoe was lost..." is the meaning implied here. Example: failure to provide airborne interceptor threats in an airborne EW trainer delimits the range of training in establishing threat priority and conducting defensive maneuvers; example: failure to provide ASW destroyer sonar detection ranges in excess of 10,000 yards compromises training in tactical decision making employing long range weapons (such as ASROC, DASH); example: failure to provide sonar classification cues delimits the capability of an ASW team trainer (e.g., ASROC/ASW Early Attack Weapon System Trainer, Device 14A2) to conduct tactical employment of a fighting ship in its full meaning. Thus, adequate specification of these elements is required so as to insure that training purpose and training objectives are achieved (thereby enhancing the transfer of training potential). Since these elements are manipulatable, they also affect the excellence of the utilization context for the sequencing of training (again, in terms of purpose and training objectives). In short, the simulation elements define what is needed in the task environment to achieve the expected transfer of training, assuming effective utilization of the device.

These controllable elements refer to the training mission environment at the trainee compartment and narrow down to three major groupings of characteristics: own-vehicle and support units; targets; and the media. Within each of these major groupings, the following subsystems are involved: sonar, radar, electronic warfare, visual real world, vehicle dynamics, and weapons. The matrix outlining the interrelationships has already been shown in Figure 11.

2.7.2.1 Levels of Fidelity

Five levels of simulation fidelity are pertinent to the human factors specification of the characteristics required to insure effective task installation for the training system under consideration. How well each simulation element is to be represented for training should be evaluated in terms of these five levels or dimensions. Table 5 describes the fidelity of simulation levels used in evaluating each of the simulation elements identified within the categories in Figure 11. For level 1, the decision is to either select or exclude the element from simulation. Based on the decision to represent an element in design, the following dimensions are then examined to determine the fidelity required to be useful for training. For level 2, the decision is to select the required value(s) for the element (for example, six levels of sea state for sonar operations); for level 3, the decision is in terms of engineering precision (for example, EW signal signatures for an airborne electronic warfare trainer); for level 4, the decision is in terms of a necessary reduction in tolerances, or a backing off from engineering fidelity (for example, radar land mass depiction at low altitudes, or elimination of a term(s) in the mathematical model for aerodynamic simulation); and for level 5, the decision deals with special features of the training system and concerns the desirability of deliberately deviating in the design of operational equipments, other than on the engineering fidelity continuum, to enhance transfer effects (for example, employing a stimulus enhancement technique on a primary visual display, or displaying alpha-numeric performance information (augmented feedback) directly on a student's CRT display).

2.7.3 Classification of Simulation Elements. The whole array of the simulation elements that must be evaluated for representation in the design of the trainee compartment to achieve control, display and procedural requirements, is presented next. These elements of simulation are organized in terms of own-ship and support units, target, and media characteristics. For each class of task element within each of these three groupings, decisions must be made about various dimensions of fidelity required. To aid in this determination, the five levels for evaluating fidelity of simulation, identified in Table 5 are used. Thus, in the following outline (Table 6), the classes of simulation elements are grouped within major subsystems applicable to the device under consideration. This is accomplished (as applicable) independently for each of the simulation areas (own-ship, target, media) since the classes of simulation elements are different for each area. Thus,

TABLE 5. FIDELITY OF SIMULATION LEVELS FOR EVALUATING SIMULATION ELEMENTS

Level	Description
1	Inclusion/exclusion of the element.
2	Representative envelope/steps/value for the element.
3	Degree of fidelity required (where engineering state-of-the-art is adequate).
4	Fidelity achievable where reduction in tolerances is required (where engineering state-of-the-art is less than adequate).
5	Deliberate departures from realism to enhance training effectiveness (deviations in configuration/operation associated with the operational system being simulated).

for example, the classes of simulation elements for the sonar subsystem are identified for own-ship and support units, again for target characteristics, and again for the simulated medium. The appropriate fidelity dimension(s) to consider is indicated (identified by corresponding number in Table 5) for each class of simulation element in each subsystem for each of the three simulation areas.

2.7.4 Output. Identification is made of the crucial factors in representing the operational environment in the trainee compartment. The functional characteristics of trainee compartment design consider most prominently the issues involved in achieving simulation fidelity in creating an environment for learning. The completion of this phase yields the following:

- Configuration of the synthetic system (in terms of the extent of representation, the hardware components in the trainee compartment, and specific equipment requirements.
- Definition of the task structure and definition of simulation elements (parameters to be simulated which govern the range and complexity of task representation in the device and which are required to achieve training purpose and the training objectives).

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS

I. OWN-VEHICLE AND SUPPORT UNITS

A. SONAR (Electronic Visual Symbol and Auditory Display)

1. OWN-VEHICLE RETURNS	(fidelity dimensions ①③)
• own-ship noise (flow noise as a function of speed, turbine noise, steam noise, noise associated with weapon actions, internal noises of crew, pumps) • wake • knuckles • torpedo hydrophone effects • countermeasures	appropriate video/audio characteristics appropriate video/audio degradation as a function of speed increase, correlated with optimum sonar speed
• cavitation (depth/speed)	own-ship cavitation sounds detectable when cursor is placed in baffles area

2. SUPPORT UNIT RETURNS	(fidelity dimensions ①③)
• support ship(s) (aspect) • effects of echo-ranging (mutual interference effects from surface ships, dipping helos, sonobuoys, submarines)	Video - appropriate blip size, shape, brightness for the vehicle, correlated with aspect Audio - appropriate echo quality, doppler effects correlated with aspect
• pings from other helicopters/submarines	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

• noise (e.g., garbled noise from underwater telephone)	
3. MALFUNCTION CAPABILITIES IN EQUIPMENT	(fidelity dimension ①)
• audio failure	
• video failure	
• automatic target following (ATF)	
• recorder failure (bearing information trace)	
• own ship course information	
• tape recorder (e.g., in submarine for turn count)	
• BT layer information (submarine)	
• loss of bug (manually trained-submarine)	
• bearing position information	
4. PPI DISPLAY CHARACTERISTICS - PERCEPTUAL REQUIREMENTS	(fidelity dimension ③)
• echo quality	
• pip quality (aspect)	
• axis angle	
• trace length	
• differential range rate	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

5. VISUAL DISPLAY REQUIREMENTS (fidelity dimension ③)
   - acuity
   - luminance
   - refresh rate (flicker)
   - contrast sensitivity
   - resolution
6. TRANSFER OF SONAR DATA TO OTHER SUBSYSTEMS (fidelity dimensions ①③)
   (e.g., to fire control subsystem)
   - range, speed, bearing, target course (manual insert)
   - generated target tracking
7. DELIBERATE DEPARTURES FROM REALISM (fidelity dimensions ⑤)
   - display of performance information (knowledge of results) to trainee (on primary display or via separate equipment)
   - coding of signals (e.g., alpha-numeric)
   - stimulus enhancement

B. RADAR (Electronic Visual Symbol Display)

1. OWN-VEHICLE RETURNS (fidelity dimensions ①③)
   - reflection echoes (surface ship)
   - wake (surface ship)
   - superstructure masking (dead zones)

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TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

• interference from other radars in own vehicle or in proximity to own vehicle	
• own vehicle depth/antenna height above water	
2. SUPPORT UNIT RETURNS	(fidelity dimensions ①③)
• surface ships, aircraft	blips proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected
• wakes (surface ships)	appearance and definition correlated with ship speed
3. PPI DISPLAYS - perceptual requirements	(fidelity dimensions ①③)
• range strobe	
• sweep line	
• offset features	
• target designation features (e.g., Hooking)	
• enhancing the signal (in operational equipment)	
4. SELF-TEST INDICATIONS	(fidelity dimensions ①②)
5. VISUAL DISPLAY REQUIREMENTS	(fidelity dimensions ③)
• acuity	
• luminance	
• refresh rate (flicker)	
• contrast sensitivity	
• resolution	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

6. MALFUNCTION CAPABILITIES IN EQUIPMENT (fidelity dimension ①)

   - partial failures
   - degrading of resolution (e.g., range, video)
   - transmitter loss

7. DELIBERATE DEPARTURES FROM REALISM (fidelity dimension ⑤)

   - display of performance information (knowledge of results) to trainee (on primary display or via separate equipment)
   - coding of signals (e.g., alpha-numeric)
     - what symbology
     - how many codes needed
   - stimulus enhancement

C. ELECTRONIC WARFARE (Electronic Visual Symbol Display)

1. OWN-VEHICLE RETURNS (fidelity dimension ③)

   - noise, interference effects (e.g., ECM emitters on board, placement of antennas aboard surface vehicle, harmonics)
   - electromagnetic interference (EMI) from on-board equipment

2. SIGNAL CHARACTERISTICS - DISPLAY PERCEPTUAL REQUIREMENTS (fidelity dimension ③)

   - pulse frequency (modulation)
   - pulse repetition frequency (PRF)
   - peak power (range between transmitter and receiver)

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

- side lobe characteristics
- antenna scan patterns (conical, lobe switching, circular, spiral, raster, sector scan, Palmer, Lewis, omnidirectional), involving sequence of events and associated audio tones
- scan period
- pulse width
- polarization
- beam width
- bearing
- rise and fall time
- PRF jitter
- variable pulse trains

3. MALFUNCTION CAPABILITIES IN EQUIPMENTS (fidelity dimension ①)

4. JAMMING CAPABILITY (fidelity dimensions ①②)
   - brute force (types, e.g., CW noise, FM; barrage)
   - deceptive
   - look-through capability
   - power (output variation)
   - capability for coverage of enemy
   - individual student jamming capability

5. EXPENDABLES DELIVERY (fidelity dimensions ①②)
   - chaff/rope
   - decoys

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

6. VISUAL DISPLAY REQUIREMENTS (fidelity dimension ③)

- acuity
- luminance
- refresh rate (flicker)
- contrast sensitivity
- resolution

7. DELIBERATE DEPARTURES FROM REALISM (fidelity dimension ⑤)

- display of performance information (knowledge of results) to trainee (on primary displays or via separate equipment)
- masking of displays in universal/generalized trainers not utilized in specific mission context

D. VISUAL REAL WORLD (fidelity dimensions ①②③④)

1. AIR TO GROUND REQUIREMENTS

- artifacts to represent (buildings, vehicles, bridges, etc.)
- areas/elevations
- size changes/perspective (function of range/altitude)
- complexity of visual detail
- figure-ground characteristics (object(s) on land/water)
- scale
- display of weapon effects

2. AIR TO AIR REQUIREMENTS

- target characteristics

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

  - size/aspect changes (function of range/altitude)
  - relative motion
- independent motion in the field
- scale

3. AIR-TERMINAL AREA

- visual scene requirements (e.g., carrier deck details, horizon, carrier wake, carrier reference to horizon; runway details)
- angle of view
- depth of field (constraints)
- size/perspective/relative motion changes (function of speed/altitude/translation of landing vehicie)
- color of the surround
- scale

4. VISUAL FACTORS OF OBJECTS

- acuity
- luminance
- resolution
- color

5. OPTICAL CONSIDERATIONS IN PERISCOPE SIMULATION

- operating modes (e.g., high, low power)
- exit pupil size
- elevation/depression (altiscope)

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

- visual angle
- target range (stadimeter/telemeter)
- seascape/landmass (relative movement between own ship and seascape)
- perspective of target images displayed
- background/special effects (effect of earth curvature, i.e., variable relationship between fixed horizon and moving target
- variable scope exposure as function of keel depth (target visibility and "height of eye" of observer)

6. COMPATIBILITY OF VISUAL REAL-WORLD SCENE
    - with movement of own-vehicle
    - with other displays/instruments
7. VISUAL SCENE PROGRAMING
(Programed, semi-programed, non-programed)
8. TARGET MOVEMENT AS FUNCTION OF RANGE, BEARING, ALTITUDE, ASPECT CHANGES

E. VEHICLE DYNAMICS

1. OWN-VEHICLE CHARACTERISTICS (fidelity dimensions ①②)
    - type of vehicle/characteristics
        - speed range
        - ordered course
        - acceleration/deceleration characteristics
        - turn rate/radius

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

    - dive/climb rate
    - ordered depth/altitude
    - vehicle response lags

2. SUPPORT UNITS CHARACTERISTICS (fidelity dimensions ①②⑤)

   - type and number
     - assist ships (e.g., SAU destroyer units; aircraft for VECTACS)
     - aircraft (e.g., formations, remote control (DASH), vehicles)
     - aircraft carrier(s)
   - vehicle characteristics
     - speed range
     - ordered course
     - acceleration/deceleration
     - turn rate/radius
     - dive/climb
     - vehicle response lags

3. RELATIVE MOTION OF VEHICLES DISPLAYED (fidelity dimensions ②⑤)

4. PLATFORM MOTION REQUIREMENTS (fidelity dimensions ①③④)

   - motion parameters required (degrees of freedom)
   - values for defined motion parameters
   - acceleration tolerances (onset, washout rates)

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

- random forces (turbulence, vibration, jerk)
- control/display compatibility (visual-motion integration)

5. AERODYNAMIC SIMULATION (fidelity dimensions ③④⑤)

- mathematical modeling requirements
    - dynamic vs. kinematic (computer controlled) models (i.e., trainee inputs in control forces such as controlling an aircraft, vs. trainee ordering of the commands while not in dynamic response loop, such as an EW trainee conducting an evasive maneuver in response to an airborne interceptor, i.e., he only orders the maneuver--the simulated own-aircraft completes the maneuver and automatically returns to the previous track).
    - definition and selection of terms in the equation of motion to optimize the equation, i.e., what terms to include (linear rates and velocities, linear and angular accelerations)
- dynamic control force requirements
    - aircraft characteristics (stick forces)
- controls-displays compatibility
    - coupling of aerodynamic, visual and motion functions

6. VEHICLE SOUNDS (AUDITORY) (fidelity dimensions ①②)

- ambient noise (e.g., cockpit noises, changes in submarine configuration, steam and flow noises in submarine)
- engine sounds (e.g., turbine power, rotor engagement compressor stall, failure characteristics)
- sounds related to pertinent events in mission context (e.g., tire screech on landing impact, turbine changes)

7. OLFACTORY CUES (fidelity dimensions ①②③)

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

F. WEAPON SUBSYSTEMS

1. WEAPON TYPES AND NUMBER (fidelity dimensions ①②)
   - loadout
   - mix
2. WEAPON REACTIONS (own-vehicle, support vehicles) (fidelity dimensions ①②)
   - characteristics
     - trajectory programs
     - runout time/time in flight and patterns/in-flight control (wire guided)
     - firing pattern
     - flexibility (e.g., safety, depth/speed on launch)
     - special features of weapon
     - homing characteristics of torpedo (wire, pre-set)
     - display of weapon aiming/trajectory
   - effectiveness indications (course, hit/miss)
3. MATERIAL COUNTERMEASURES (fidelity dimensions ①③)
   - expendables
     - types
     - loadouts
     - employment patterns
   - towed noisemakers

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

  - types
  - streaming and activation
- non-towed noisemakers (e.g., decoys)

4. FIRE CONTROL DISPLAY REQUIREMENTS (fidelity dimensions ①②)

- sensor data handover
- range and bearing indication of target (target position)
- own-vehicle display (symbol)
- cursor dynamics and control
- information feedback, equipment assists
- data link for airborne fire control
- status information requirements
  - channel/tube assignments and loading
  - weapon status (including malfunctions)
  - rail status/tube status (up/down, loaded/empty, flooded, door open/shut)
- visual display factors

II. TARGET

A. SONAR

1. TARGET CHARACTERISTICS (fidelity dimensions ①②)

- number of targets to represent at a given time in the mission environment
- classes of targets

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

• target appearance /disappearance/attenuation as a function of range and sea conditions	
• target movement as function of range, bearing, aspect changes	
2. TARGET VEHICLE RETURNS	(fidelity dimensions ①③)
• aspect (bow, beam, stern)	Video - appropriate blip size, shape and brightness persistence for brightness modes Audio - doppler effects (up, down, no) via increase/no increase/decrease in pitch over transmission frequency
• cavitation effects • hydrophone effects from torpedo	Video - appropriate noise spoke for speed, depth, range and BT envelopes Audio - appropriate audio characteristics for speed, depth, range and BT envelopes
• knuckles • wakes	Video - appropriate blip size, shape, and brightness persistence for brightness modes Audio - appropriate audio characteristics
• tonals	specific frequency/frequency band which stands out from general increase in noise levels on a bearing
• vehicle sounds (screw beat (turns per knot ratios), machinery noises, housekeeping noises)	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

3. DELIBERATE DEPARTURES FROM REALISM (fidelity dimension ⑤)

B. RADAR

1. TARGET CHARACTERISTICS (fidelity dimensions ①②)

- total number of targets to represent in mission environment
- classes of targets
- number of targets displayed simultaneously/instantaneously (number that the trainee is capable of processing in his span of control)
- target appearance/disappearance/attenuation as a function of range/altitude and environmental conditions (e.g., radar fades, height of antenna)
- capability for add-on of new targets (for updating)

2. TARGET RETURNS (fidelity dimensions ① ③)

- submarine

- surfaced	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected
- periscope depth/ snorkel	
- feathers	correlated with submarine speed at periscope depth

- aircraft

- speed and maneuvers	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

- vectoring of aircraft in IFR departure (GCA-CCA)	
- relative motion	
- lock-on indications	
- target identification (e.g., SIF)	
• surface vehicle	
- speed and maneuvers	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected
3. LAND MASS SIMULATION	(fidelity dimensions ①③④)
• characteristics	
- smallest target size defined	
- radar modes defined	
- aspect angle/shadowing	
- beam width (vertical/horizontal)	
- scintillation (change in target brightness)	
• accuracy of moving across land mass display	
• far shore brightness (elevation) (e.g., ring of shoreline, perimeter of city, form of aspect angle)	
• range of degradation	
• definition of gray steps (altitude depiction-ability to resolve object height)	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

4. TARGET DISTORTIONS (fidelity dimensions ①②)
   - garbling (signal overlap)
5. DELIBERATE DEPARTURES FROM REALISM (fidelity dimensions ⑤)
   - slaved/non-dynamic targets

C. ELECTRONIC WARFARE

1. TARGET CHARACTERISTICS (fidelity dimensions ①②)
   - total number of emitters to represent in the mission environment
   - classes/types of emitters in the mission environment
     - hostile and friendly mix (hostiles: AAA, SAM, air to surface missiles, Early warning, height finders, track-while-scan, acquisition radars, airborne interceptors, GCA, IFF/SIF and telemetry signals, navigational signals), communications signals (e.g., modulation, CW, amplitude frequency, single side band, etc.)
     - maneuverable emitters (type; heading, altitude and speed envelopes)
   - number of emitters displayed simultaneously/instantaneously (number that the trainee is capable of processing in his span of control)
   - target appearance/disappearance/attenuation as a function of range and bearing and environmental conditions
2. EMITTER RETURNS (fidelity dimensions ①③)
   - signal signatures per class of emitter

LE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

- signal jamming (different forms of voluntary jamming, e.g., broad band, spot, fast swept frequency jamming, modulated jamming, transmission deception)
- emitter distortions
  - interference
  - simultaneity of signals (overlap of signals)
- signal characteristics (shape, patterning of signals as a function of range)
- audio characteristics
  - multiple audio
  - noise
- target reactions to evasive maneuvers of aircraft
  - loss and reacquisition
  - deception due to expendables
- indication of weapon effect (hit/miss of enemy missile)
- indication of jamming (e.g., in cockpit)

. VISUAL REAL WORLD (fidelity dimensions ②③④)

1. TARGET CHARACTERISTICS

- size, shape, aspect, silhouette (configuration)
- color, visibility
- size changes as function of range
- movement/movement patterns
- clutter

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

2. TARGET DETECTABILITY
   - figure/ground (seascape, shoreline)

E. WEAPONS

1. WEAPON TYPES AND NUMBER (fidelity dimensions ①②)
   - loadout
   - mix

2. WEAPON REACTIONS (fidelity dimensions ①②)
   - characteristics
     - hydrophone effects
     - firing pattern
     - special features of weapon
   - effectiveness indication (hit, course)

III. MEDIA

A. SONAR

1. ENVIRONMENT (fidelity dimensions ①②)
   - wind direction/speed
   - sea state
   - thermal gradient
   - bottom depth/bottom characteristics
   - ambient water noises
   - altitude/ocean depth
   - land mass

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

2. RANGE	(fidelity dimension ②)
• envelope of detection ranges achieved operationally (appearance/disappearance/attenuation of targets)	
3. NON-TARGET RETURNS (Classification Cues)	(fidelity dimensions ①③④)
• reverberations • bottom returns	appropriate video and audio characteristics
• natural (fish, whale, reef, pinnacle) • obstructions (wrecks)	Video - appropriate blip size, shape, brightness for the brightness mode Audio - appropriate doppler effects, echo quality
• torpedo hydrophone effects (submarine)	appropriate noise spoke, appropriate audio characteristics
• cannisters, jammers, decoys (submarine launched)	appropriate video and audio characteristics
4. BACKGROUND CLUTTER/ NOISE ON DISPLAY	(fidelity dimensions ①③)
5. INTERFERENCE EFFECTS FROM MULTI-SHIP ENVIRONMENTS	(fidelity dimensions ①③)
B. RADAR	
1. ENVIRONMENT	(fidelity dimensions ①②)
• wind direction/speed	
• sea state	
• altitude	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

• land mass/elevations	
• artifacts (stations, buildings, etc.)	
2. RANGE	(fidelity dimension ②)
• envelope of detection ranges achieved operationally (appearance/disappearance/attenuation of targets)	
3. NON-TARGET RETURNS	(fidelity dimensions ①③)
• second sweep echoes	blip characteristics of operational environment
• radar decoys	
• sea returns	density and brightness correlated with sea state and range
• cloud cover	
• land mass characteristics	
4. BACKGROUND CLUTTER/ NOISE ON DISPLAY	(fidelity dimensions ①③)
5. INTERFERENCE EFFECTS FROM MULTI-SHIP ENVIRONMENTS	(fidelity dimensions ①③)
C. ELECTRONIC WARFARE	
1. ENVIRONMENT	(fidelity dimensions ①②)
• wind direction/speed	
• altitude	
• weather (temperature, pressure, humidity)	

TABLE 6. CLASSIFICATION OF SIMULATION ELEMENTS (Continued)

2. RANGE (fidelity dimension ②)
    - envelope of detection and lock-on ranges achieved operationally (appearance/disappearance/attenuation of targets)

3. NON-EMITTER RETURNS (fidelity dimensions ①③)

4. BACKGROUND NOISE/ INTERMITTENCY ON DISPLAYS; AUDIO INTERFERENCE (fidelity dimensions ①③)

5. INTERFERENCE EFFECTS (EMI) (fidelity dimensions ①②)

D. GEOMETRY OF THE ENGAGEMENT (fidelity dimensions ①②⑤)

- Tactical environment (initial conditions and enroute operations)
- counteractions and weaponry of adversary
    - characteristics of adversary vehicles
    - display of enemy actions (deployments, weapon usage)
    - display of enemy weapons action (e.g., water splash of surface launched air-to-water missile)
- adversary tactics (intelligence information, order of battle)

E. SCALE OF THE ENGAGEMENT (fidelity dimension ②)

- ocean area
- air area

- Special features in trainee compartment design which presumably will enhance training value in terms of greater transfer of training to the operational system.

2.8 PHASE 5B: THE MANAGEMENT OF TRAINING--STRUCTURING, CONTROLLING AND MONITORING TRAINING AT THE INSTRUCTOR STATION. In addition to the design issues involved in installing the environment in which learning can take place (simulation of the trainee compartment), there are design issues associated with the structuring, monitoring, evaluation and control of training. This involves the management of training at the instructor station, and concerns how the device will be utilized as a training tool.

The human factors design of the instructor station complex emphasizes the concept of design for training utilization. Given the environment for learning (trainee compartment design), the concern is for how the synthetic environment will be used for training and for creating and monitoring training situations in order to shape student behaviors and to optimize the training strategies for students during the course of instruction. The design requirement is to provide a capability for structuring training so that the important mission and system events can be installed and controls provided to insure that these events occur in prescribed ways at prescribed times. This calls for a flexibility in training capability so that the defined situations can occur at the desired times in order to satisfy the training objectives.

A human factors design pathway is developed to provide an instructional capability consistent with the training purpose and the design of the trainee compartment. The approach consists of evaluating the information requirements for the instructor station and examining the design alternatives, then correlating the two in order to select the design options most relevant to achieving the desired training. Defining the design pathway involves evaluation within the following areas:

a. The training system modes of operation
b. Analysis of instructor functions
c. Instructor requirements
d. Display requirements
e. Control requirements
f. Monitoring and control of training (enroute during the exercise)
g. Pre-mission requirements
h. Post-mission requirements
i. Measurement system requirements
j. Communications requirements
k. Overall layout and workplace requirements

2.8.1 Training System Modes of Operation. The initial consideration involves specifying the operating modes at the instructor console in controlling, monitoring and evaluating training, and in the instructing of students. These modes, which range from strictly manual operation through completely automated operation, vary considerably in required hardware and in computer programing, and hence must be carefully specified at the outset.

Two concepts that are recognized as possessing substantial importance to instructor station design are, the full automation of instructor functions and the generalized (modular) construction of the instructor station. The desirability of these two design concepts is tacitly assumed throughout this phase on instructor station design. Although the state-of-the-art has not advanced sufficiently to suggest these as ordinary design options, they nevertheless, represent important goals to be achieved as data and technique are forthcoming from research and application. Research on the automation of instructor functions is described in Section III of this report.

2.8.1.1 Manual Mode. Decisions must be made about instructor involvement (controls and displays) in pre-exercise briefing, in setting up the initial conditions for any training exercise, in the control of mission events via a script of event setups during the running of the mission scenario, and in post-exercise critique. Means for evaluating trainee performance must also be specified, ranging from subjective judgments about performance via displayed information and trainee actions and communications, to recorded measurement information. (Requirements for a measurement system are discussed subsequently in Section 2.8.9).

2.8.1.2 Automated Mode. The selection of instructor functions to automate involves the following considerations.

- Preprogramed mission scenarios

  An important feature in design is the use of automated, standardized preprogramed training exercises with the provision for instructor intervention in prescribed ways in the scenario to control the training process. To be considered are control and display capabilities permitting scenario alteration at certain times during a mission (as a function of stage of training) in order to develop a strategy for training each assigned student to achieve the training objectives for a sequence or course of instruction. In every case, the preprogramed mission scenarios should provide a series of exercises graduated in difficulty.

- Incorporation of automatic assists

  This involves design to relieve the instructor of the more "clerical" duties in order to enhance systematic instruction. It is based largely on automated student-performance monitoring and evaluation involving an automated scoring system with computer generation and display of scoring information. More precise structure and control of training is afforded the instructor by means of automated measurement.

Again, the issue of instructor intervention must be considered carefully since it is highly desirable for the instructor to exercise options, via hardware based on his judgments supported by displayed and/or recorded performance information on how well each student is doing. Under most conditions, finer control of training is afforded in this way rather than in purely manual or in fully automated control. These options (described later) enable the instructor to keep each student at "best level" of performance throughout the training sequence.

2.8.1.3 Adaptive Training Mode. A decision is also made on the extent of adaptive training desired when a partially automated (or eventually a fully automated) training system is selected. Two basic approaches to adaptive sequencing should be considered, particularly when two or more trainees are performing at once in a simulator but independently: a manual (normal) adaptive capability or an automated adaptive capability.

2.8.1.3.1 The manual (normal) adaptive training capability is defined by the options available to the instructor for keeping a student progressing through a sequence of training at his own achievement speed. Of course, this term really represents the ideal expression of training wherein a skilled instructor does his job to train a student efficiently. As such, it covers most instructional situations which, of themselves, are not dependent upon equipment assists. However, we are applying this term particularly in situations where automated assists will increase the instructor options in developing strategies to enhance the performances of a group of students undergoing simultaneous but independent training in a simulator. These options account for both the weak and for the exceptional student (individual differences among trainees). As the student progressively acquires skills, the task and mission requirements can be made increasingly more difficult. This emphasizes that the instructor, provided with the necessary student performance information, decides on the strategy and initiates the sequencing of training to accommodate each student. The instructor is continually involved throughout the mission in monitoring all critical aspects of student performance. He evaluates the performance of each student relative to the mission scenario requirements, being concerned with those who make errors in excess of preset performance tolerances and also with those who exceed scenario performance requirements. He provides the remediation necessary to correct or modify deficiencies, or advances the difficulty level for a student so that each student progresses at an optimum learning rate. A number of equipment assists are required to provide flexibility in employing the simulator for training and for unburdening the instructor. The features which enable the instructor to concentrate on his instructional duties and develop training strategies tailored to the individual students include:

- problem halt or manipulation of position in the mission profile (going back to an earlier segment) for remedial, demonstration, or reinstruction purposes
- override of defined programed mission events
- automated scoring of student error deviations from a tolerance level
- automatic halt of problem when student exceeds a defined error envelope
- on-line modification of error tolerance envelopes
- computer generated CRT displays of student performance information in all relevant instructional modes
- insertion of events in addition to the parameters in the preprogramed scenario to instruct students whose performance exceeds scenario requirements
- guidance information (cues, prompts, knowledge of results) provided the student via equipment
- hard copy records of student performance.

Automated evaluation and scoring with scoring criteria adjusted to the stage of training of each student provides error indications and information which are displayed to the instructor. He uses these directly in monitoring, evaluating and controlling each student's progress. The instructor options for achieving the manual adaptive capability (i.e., developing the training strategies) are listed below. These changes can be made to the preprogramed mission either by event or time access via displays and controls on the instructor console.

- Continue preprogramed mission, no action required.

- Provide verbal feedback of performance information to selected student based on monitored information obtained from the displays. This may be in the form of knowledge of results of performance and/or cues to the student for enhancing performance.

- Halt the problem for any or all students and provide verbal guidance, or halt the problem until all students have completed a mission phase; resume mission.

- Demonstration mode--provide a capability during the exercise to demonstrate aspects of a task or maneuver to all students or to demonstrate specific characteristics of performance for any or all students when performance is below expectations for the specific mission number; resume mission.

- Reinstruction mode--provide a capability to return to an earlier portion of the mission for any or all students when performance is below expectation for the mission. The reinstruction requires that the student perform again that which he has just completed, i.e., a segment or leg or portion of a leg.

- Error alert mode--when a student exceeds the error envelope in the mission for a class of error, a display of this information is provided the instructor and a computer-initiated problem freeze is a conventional outcome. The instructor options include: manual override of the freeze; accept freeze with procedures to continue (including the setting of new error tolerance envelopes); as well as those listed above in order to develop the training strategy for the student in question.

- Insert new events into the exercise--when a student's performance exceeds the mission scenario requirements, the instructor has the option of inserting new events in addition to those in the preprogramed scenario. This provides for a controlled increase in problem difficulty for the purpose of keeping any student at the threshold of his ability at any given time.

2.8.1.3.2 The automated adaptive training capability requires greater reliance on software whereby the computer is involved in performing the instructing functions, with the instructor serving as a system monitor.

The technique automates an important instructor function, that of problem selection (that is, progressing through a graduated series of exercises to achieve the optimum training strategy). This involves the automation of two other functions: scoring of performance so that adaptive sequencing is possible; and providing information so that the student will know where to direct effort at reducing his error rate. In describing an adaptive training system, three fundamental elements must be specified:

a. Performance measurement (continuous/ repetitive scoring of performance)

b. Adaptive variables (task modification to systematically change its difficulty)

c. Adaptive logic (the function used to automatically adjust task difficulty based upon measured performance)

The implementation of adaptive training requires that a number of problems be addressed. The problems relate to the following (these are discussed in detail in Section III).

a. Selecting Adaptive Variables . These are the parameters which may be varied to affect task difficulty. The following classes of variables are appropriate.

1) Task loading (increases in event loading, time of event introduction, insertion of events based on threat or other priorities)

2) External forcing function (e.g., turbulence on aircraft control, via frequency, amplitude bandwidth of function)

3) Noise (signal degradation)

4) Simultaneity of signals per unit time

5) Quickening of a manual control system (aiding)

6) Effective time constant (T_e)

7) Malfunctions

b. Feedback. The students must be provided information about progress throughout training, both immediately in terms of how the result of the current performance conforms to an objective standard (augmented feedback provided immediately as a performance output accrues and is identifiable), and during and after a training exercise in the form of a critique of performance.

c. Measurement. The crucial measures must be identified for automatic scoring. Since performance envelopes can be objectively defined, measurement of deviation from them can be accomplished. In a digital computer-controlled system, all parameters of activity are already being computed; thus, the measurement becomes a comparison of actual with desired/ideal performance.

d. Adaptive Logic. In adaptive training, problem difficulty level is set in response to student performance as reflected in some form of error score. The problem of error scoring for adaptive purposes (as opposed to scoring for purposes of student feedback) would be the major problem area for programing, in that adequate guidance from a real-world model or from research is lacking. Initially, values must be selected on a somewhat arbitrary basis until their suitability can be established in the actual training setting.

2.8.2 Analysis of Instructor Functions. Once the decision is made defining the mode(s) of training device operation, an identification and analysis of instructor functions is undertaken for the activities involved in pre-exercise setup, enroute exercise operations, and post-exercise operations. The display, control and communications requirements are specified for the following classes of operations and instructional functions.

- Initialize system, confidence checks
- Initialize system for mission operation
- Selection/modification/construction of new scenarios (off-line) (where applicable)
- Student briefing (including demonstration mode, where applicable)
- Setup of initial conditions of exercise (manually or via address of preselected data sets when preprogramed scenarios are not employed)
- Monitor and control of student(s) performance (provisions for the following):

  - Exercise start (COMEX)
  - Exercise freeze
  - Manual override of preprogramed mission/scenario (as applicable)
  - Demonstration mode
  - Error alert mode (computer indication to the instructor that student performance is out-of-tolerance due to excessive error)
  - Insertion of new events into standardized preprogramed scenario (as applicable)
  - Control of events throughout non-programed mission (time and event control of problem manipulatables) (as applicable)
  - Problem speed control (real time, slower than, or faster than real time)
  - Communications with trainees; and with device operator, remote instructor(s), as applicable
  - Instructional assists for unburdening the instructor
- Evaluation and scoring requirements
  - Measurement system
- Mission termination
- Post-mission critique
  - Equipments for critique (e.g., projection system; audio, audio/video recording)
  - Hard copy critique printouts (form/content)
  - Time and event printout of the training mission (form/content of hard copy for school records)

A functional overview of the instructional involvement in the training system should be undertaken to consolidate the thinking on the design philosophy and to aid in the further definition of design requirements for the instructor station. A most useful form is a functional flow diagram of the operating requirements on the instructional staff for the complete training mission cycle. An example of this functional flow analysis is shown in Figure 12 for an airborne Electronic Warfare Trainer.[1]

The display, control and communications requirements for the identified instructor functions can now be analyzed in the detail necessary to achieve the desired design pathway for the instructor station. Table 7 provides an example of the level of analysis that will serve the purpose for specifying the functional characteristics of design. The example is for the same airborne electronic warfare trainer cited above.

2.8.3 Instructional Staff Requirements. The makeup of the instructional staff must be defined. This includes the number of instructors (based on workload estimates), and types of instructors to be used, with their qualifications and prerequisites for assignment to the training program. Distinctions should be made about type of, and assignment of instructors. Usually, three categories can be defined: the central or chief instructor, located at the master console(s); the device operator, located at the computer complex, who assists in operating the training system; and remote instructors, located in or adjacent to specific trainee compartments (or also at the central instructor station) to monitor performance and provide instructional support as required.

An important consideration is the specification of instructor to student ratios, particularly in multi-student situations where each student performs independent of the others.

2.8.4 Display Requirements. A key requirement in instructor station design is the efficient display of student performance information. The specification of display requirements is largely dependent on the information requirements in terms of, content; amount, variety, and speed of information change; complexity; and the number of trainees and trainee stations involved (multi-trainee stations such as found in tactical team trainers or independent multi-cockpit devices). In short, an organized, unambiguous, fast-access information format is desired commensurate with the device under consideration.

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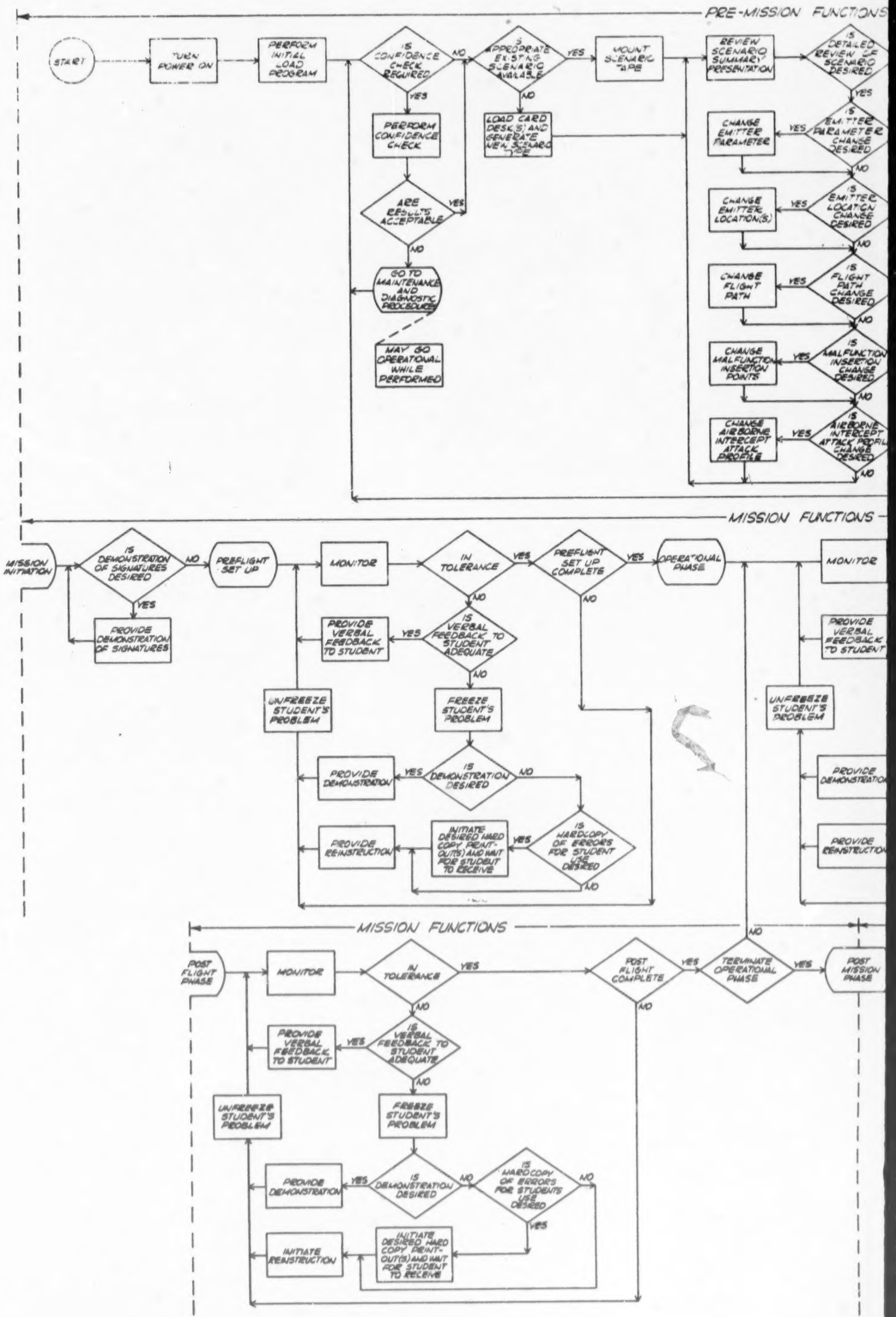
[1] The design is for an Air Force Airborne Electronic Warfare training system proposed to simulate the major current and predicted mission environments. It exemplifies a semi-automated system (preprogramed mission scenarios modifiable at the instructor station; automated monitoring, evaluation and scoring). Four independent student stations can be handled during a training exercise by one instructor.


PRE-MISSION FUNCTIONS
START
TURN POWER ON
PERFORM INITIAL LOAD PROGRAM
IS CONFIDENCE CHECK REQUIRED
NO
YES
PERFORM CONFIDENCE CHECK
ARE RESULTS ACCEPTABLE
YES
NO
GO TO MAINTENANCE AND DIAGNOSTIC PROCEDURES
MAY GO OPERATIONAL WHILE PERFORMED
IS APPROPRIATE EXISTING SCENARIO AVAILABLE
YES
NO
LOAD CARD DESK(S) AND GENERATE NEW SCENARIO TAPE
MOUNT SCENARIO TAPE
REVIEW SCENARIO SUMMARY PRESENTATION
IS DETAILED REVIEW OF SCENARIO DESIRED
YES
IS EMITTER PARAMETER CHANGE DESIRED
YES
CHANGE EMITTER PARAMETER
NO
IS EMITTER LOCATION CHANGE DESIRED
YES
CHANGE EMITTER LOCATION(S)
NO
IS FLIGHT PATH CHANGE DESIRED
YES
CHANGE FLIGHT PATH
NO
IS MALFUNCTION INSERTION CHANGE DESIRED
YES
CHANGE MALFUNCTION INSERTION POINTS
NO
IS AIRBORNE INTERCEPT ATTACK PROFILE CHANGE DESIRED
YES
CHANGE AIRBORNE INTERCEPT ATTACK PROFILE
NO
MISSION FUNCTIONS
MISSION INITIATION
IS DEMONSTRATION OF SIGNATURES DESIRED
NO
YES
PROVIDE DEMONSTRATION OF SIGNATURES
PREFLIGHT SET UP
MONITOR
IN TOLERANCE
YES
NO
PREFLIGHT SET UP COMPLETE
YES
NO
OPERATIONAL PHASE
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENT'S PROBLEM
IS DEMONSTRATION DESIRED
YES
PROVIDE DEMONSTRATION
NO
IS HARDCOPY OF ERRORS FOR STUDENT USE DESIRED
YES
INITIATE DESIRED HARD COPY PRINT-OUT(S) AND WAIT FOR STUDENT TO RECEIVE
PROVIDE REINSTRUCTION
NO
MONITOR
PROVIDE VERBAL FEEDBACK TO STUDENT
UNFREEZE STUDENT'S PROBLEM
PROVIDE DEMONSTRATION
PROVIDE REINSTRUCTION
MISSION FUNCTIONS
POST FLIGHT PHASE
MONITOR
IN TOLERANCE
YES
NO
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENT'S PROBLEM
IS DEMONSTRATION DESIRED
YES
PROVIDE DEMONSTRATION
NO
IS HARDCOPY OF ERRORS FOR STUDENTS USE DESIRED
NO
YES
INITIATE DESIRED HARD COPY PRINT-OUT(S) AND WAIT FOR STUDENT TO RECEIVE
INITIATE REINSTRUCTION
POST FLIGHT COMPLETE
YES
NO
TERMINATE OPERATIONAL PHASE
YES
NO
POST MISSION PHASE

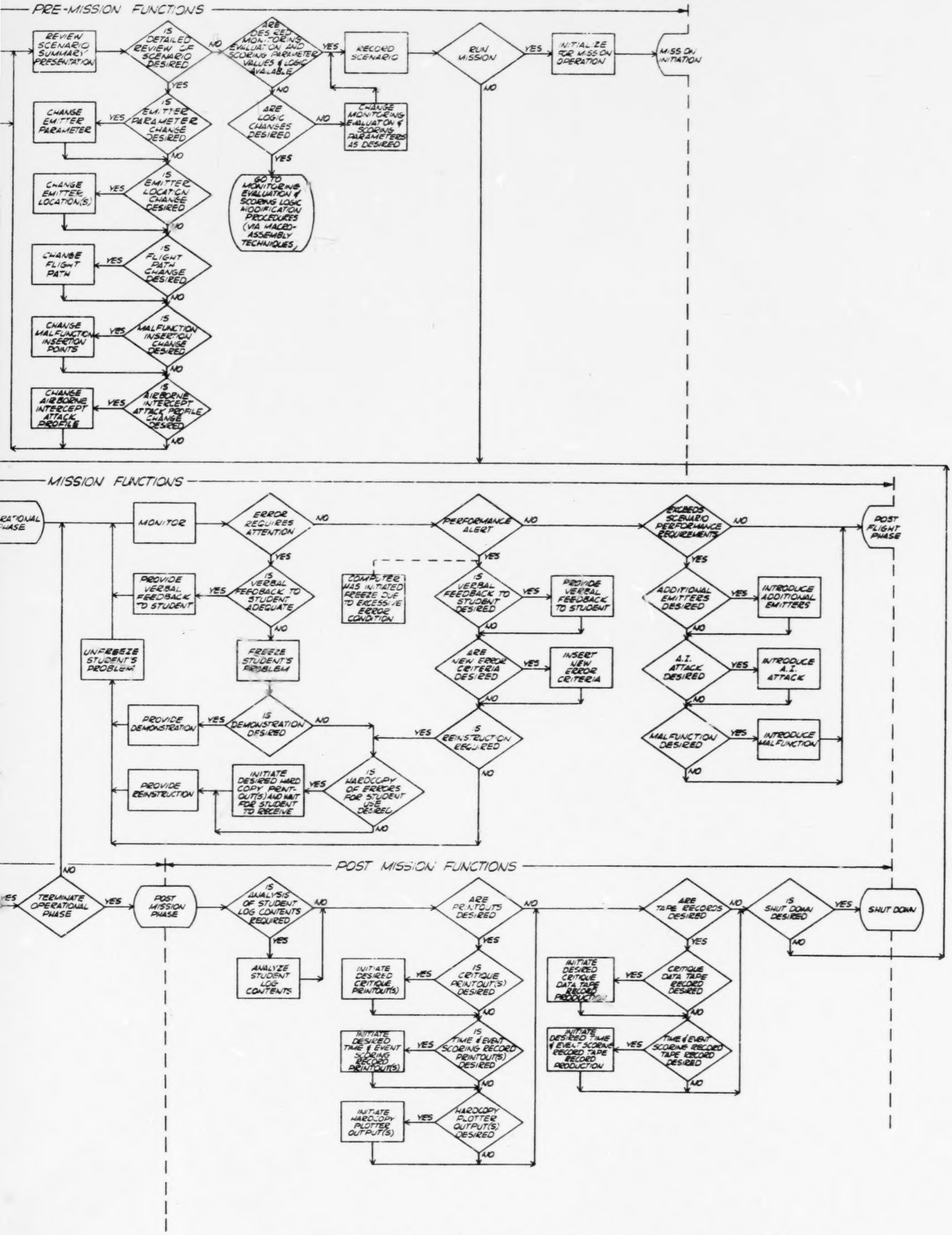

PRE-MISSION FUNCTIONS
REVIEW SCENARIO SUMMARY PRESENTATION
IS DETAILED REVIEW OF SCENARIO DESIRED
NO
YES
ARE DESIRED MONITORING, EVALUATION AND SCORING PARAMETER VALUES & LOGIC AVAILABLE
YES
RECORD SCENARIO
RUN MISSION
YES
INITIALIZE FOR MISSION OPERATION
MISSION INITIATION
NO
CHANGE EMITTER PARAMETER
YES
IS EMITTER PARAMETER CHANGE DESIRED
NO
ARE LOGIC CHANGES DESIRED
NO
CHANGE MONITORING EVALUATION & SCORING PARAMETERS AS DESIRED
YES
GO TO MONITORING EVALUATION & SCORING LOGIC MODIFICATION PROCEDURES (VIA MACRO-ASSEMBLY TECHNIQUES)
CHANGE EMITTER LOCATION(S)
YES
IS EMITTER LOCATION CHANGE DESIRED
NO
CHANGE FLIGHT PATH
YES
IS FLIGHT PATH CHANGE DESIRED
NO
CHANGE MALFUNCTION INSERTION POINTS
YES
IS MALFUNCTION INSERTION CHANGE DESIRED
NO
CHANGE AIRBORNE INTERCEPT ATTACK PROFILE
YES
IS AIRBORNE INTERCEPT ATTACK PROFILE CHANGE DESIRED
NO
MISSION FUNCTIONS
RATIONAL PHASE
MONITOR
ERROR REQUIRES ATTENTION
NO
PERFORMANCE ALERT
NO
EXCEEDS SCENARIO PERFORMANCE REQUIREMENTS
NO
POST FLIGHT PHASE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
YES
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
NO
COMPUTER HAS INITIATED FREEZE DUE TO EXCESSIVE ERROR CONDITION
YES
IS VERBAL FEEDBACK TO STUDENT DESIRED
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
YES
ADDITIONAL EMITTERS DESIRED
YES
INTRODUCE ADDITIONAL EMITTERS
NO
UNFREEZE STUDENT'S PROBLEM
FREEZE STUDENT'S PROBLEM
ARE NEW ERROR CRITERIA DESIRED
YES
INSERT NEW ERROR CRITERIA
NO
A.I. ATTACK DESIRED
YES
INTRODUCE A.I. ATTACK
NO
PROVIDE DEMONSTRATION
YES
IS DEMONSTRATION DESIRED
NO
YES
IS REINSTRUCTION REQUIRED
MALFUNCTION DESIRED
YES
INTRODUCE MALFUNCTION
NO
PROVIDE REINSTRUCTION
INITIATE DESIRED HARD COPY PRINT-OUT(S) AND WAIT FOR STUDENT TO RECEIVE
YES
IS HARDCOPY OF ERRORS FOR STUDENT USE DESIRED
NO
NO
POST MISSION FUNCTIONS
NO
YES
TERMINATE OPERATIONAL PHASE
YES
POST MISSION PHASE
IS ANALYSIS OF STUDENT LOG CONTENTS REQUIRED
NO
ARE PRINTOUTS DESIRED
NO
ARE TAPE RECORDS DESIRED
NO
IS SHUT DOWN DESIRED
YES
SHUT DOWN
YES
ANALYZE STUDENT LOG CONTENTS
YES
YES
NO
INITIATE DESIRED CRITIQUE PRINTOUT(S)
YES
IS CRITIQUE PRINTOUT(S) DESIRED
NO
INITIATE DESIRED CRITIQUE DATA TAPE RECORD PRODUCTION
YES
CRITIQUE DATA TAPE RECORD DESIRED
NO
INITIATE DESIRED TIME & EVENT SCORING RECORD PRINTOUT(S)
YES
IS TIME & EVENT SCORING RECORD PRINTOUT(S) DESIRED
NO
INITIATE DESIRED TIME & EVENT SCORING RECORD TAPE RECORD PRODUCTION
YES
TIME & EVENT SCORING RECORD TAPE RECORD DESIRED
NO
INITIATE HARDCOPY PLOTTER OUTPUT(S)
YES
HARDCOPY PLOTTER OUTPUT(S) DESIRED
NO

Figure 12. Functional Flow Analysis for EW Trainer

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
Pre-mission system setup				
System initialization	Power on indication	Power on controls	Interaction with operator	
System confidence check	Display of the advisability of confidence check; display indication that system is in tolerance or that maintenance is required	Controls to initiate confidence check	Operator, all students	Accept/reject confidence check
Initial program load		(Automatic load control at computer)	Operator	Accomplished by operator
Initialize system for mission operation		Mission initiation control	Operator, all students	Preparatory to off-line scenario modifications, or new scenario construction, or to existing scenario selecting and immediate on-line commencement of training mission

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
Pre-mission scenario modification				
Modify existing mission scenario (off-line)	Designation of scenario number	Controls to initiate scenario number	Operator	Selection of existing preprogramed mission scenario that is most like that desired. Make desired changes in emitter parameters, emitter location, flight path, malfunction insertion and/or airborne interceptor profile change
	Emitter parameter display Emitter location display	Controls to obtain specific displayed information		
	Situation display of emitter placement and flight path	Controls to select appropriate areas in the scenario for modification and enter the modifications		
	System block diagram display and display of types of malfunction that can be introduced	Controls to correct entries if those made are in error or further change is desired		Operator mounts/demounts tapes

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
	Display of logic and the parameters associated with automatic monitoring evaluation, and scoring	Controls for playback of scenario, at rates of lx, 2x, 4x		Operator actuates remote key switch at his console
	Stylized spectrum and D F displays and/or situation display of aircraft track	Controls to initiate recording of approved scenario		
Construct new scenarios	Designation of scenario number	Controls to assign scenario number	Operator	Need for new scenario to meet desired training objectives
	Emitter parameter display Emitter location display	Controls to obtain specified displayed information		Enter emitter parameter, emitter locations, flight paths, malfunction insertion, airborne interceptor profiles
	Situation display of emitter placement and flight path	Controls to enter parametric and other data		

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
	System block diagram display and display of types of malfunction that can be introduced	Controls to correct entries if those are made in error or if further change is desired		Operator mounts/demounts tapes
	Display of logic and the parameters associated with automatic monitoring, evaluation, and scoring	Controls for playback of scenario at rates of 1/4x, 1/2x, 1x, 2x, 4x		Operator actuates remote key switch at his console
	Stylized spectrum and DF displays and/or situation display of aircraft track	Controls to initiate recording of approved scenario		
Select existing preprogramed scenario tape	Display of available tapes Designation of scenario number Stylized spectrum and DF displays Situation display of mission scenario	Controls to initiate scenario numbers Controls for real time/fast time playback of scenario	Operator	Desired preprogramed scenario exists on tape(s). Ready to begin on-line operations for student training/evaluation mission

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
Operational phase				
(Enroute mission operations)				
Demonstration of signal signatures	Displays for choice or preprogramed emitters	Controls to display signal tapes	Students - Information on demonstration	Occurs after initialization of system for mission operation. Problem may be in freeze mode or progressing from time "0"
	Display of signals selected Display of modes of signal signature	Controls to display signal signatures for each type of signal	- Guidance (cues, knowledge of performance information)	
	Stylized spectrum and DF displays	Controls initiate selected signals	- Remote instructors	Purpose of demonstration to provide instruction to students in initial training on what will occur in the mission (maximum assistance)
	Situation display of mission scenario	Controls to change signal display to student		
Performance monitoring and evaluation	Display of classes of error in switch settings (in pre-flight	Controls for readout on display	Students, remote instructors	Provide information to instructor so that option can be exercised on

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
	setup sequence of switch positioning, errors of omission, incorrect settings)	Controls for selecting specific error indications per class of error (pre-flight setup and during operational phase)		instructional actions (see performance monitoring and control functions)
	Display of specific error indication by class (pre-flight setup)			
	Display of classes of error during operational phase (in emitter environment)			
	Display of specific error indication by class (operational phase)			Classes of error: Switch settings in pre-flight setup
	Stylized spectrum and DF display			Transmitters
				Receivers

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
	Situation display of mission scenario			
Performance monitoring and control	Display of classes of error during operational phase	Controls for error readout on display	Students - Information relay	Instructor options in developing a strategy for the sequencing of training independently per student
	Display of specific error indication by class	Controls for selecting specific errors	- Guidance (cues, knowledge of performance information)	
	Emitter parameter display			No action required, continue as programed
	Emitter location display	Manual override control (of automatic problem halt)	Remote instructors	Student error correction provide verbal feedback of performance information on error (knowledge of results and/or cues for enhancing performance) may or may not require problem halt
	Display of emitter characteristics for demonstration	Problem halt/ start controls		
	Stylized spectrum and DF displays	Controls to insert new error criteria for performance alert condition		
	Situation display of aircraft tracks and emitter placement; total scenario			Demonstration-problem halt and reinitiate mission after demonstration

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
		Controls to select and initiate signal(s) for demonstration mode		
	System block diagram display and display of types of malfunctions that may be introduced			
	Indication of performance alert (automatic halt of problem)	Controls to change the signal mode (demonstration)		Reinstruction (problem halt and restart) to refly a phase or portion of phase of scenario
		Controls to change the selection of signals (demonstration)		Performance alert (automatic computer halt) occurs when a student exceeds the error envelope for a class of error in the mission. Instructor may manually override, demonstrate, or reinstruct
		Controls to reposition student to refly a flight segment (or portion thereof)	Operator (activates remote key switch at operator console)	

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
		Controls for entering new emitter parameters (non-programed)		
		Controls for entering in-flight malfunction (preprogramed)		Insertion of new emitter characteristics when student performance exceeds scenario requirements
		Controls for entering airborne intercepts (preprogramed)		Insertion of variable malfunctions when student performance exceeds scenario requirements
				Insertion of airborne intercepts when student performance exceeds scenario requirements
Communications (internal and external)	Indications of channel selection	Channel selectors	Students Remote instructors Operator	

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
			External	
Termination of operational phase	Status of each student in mission scenario Display of information relevant to terminating operational phase	Controls for obtaining status on all subjects Controls for initiating post-mission phase	Students Remote instructors	All decisions made relative to instruction (demonstration, reinstruction, insertion of additional emitters/airborne intercepts/malfunctions)
Post-mission phase				
Post-mission operations	Display of types of printouts available Display of printout; format, and content options Display to indicate what types of tapes are available for recording Displays of tape content options	Controls to select the types of printouts desired Controls to select format and content options Controls to correct errors made in selection	Operator	Operator attends to printer, and mounts/demounts tapes

TABLE 7. INSTRUCTOR FUNCTION ANALYSIS (Continued)

Function	Display Requirements	Control Requirements	Communications Requirements	Remarks
		Controls to select types of tapes to record		
		Controls to select content to be recorded		
System shut-down	Display indication of completion of system function	Controls to shut-down system or to return to system initiation phase	Operator	Operator is instructed to shut down the system

2.8.4.1 What Must Be Displayed. The information classes to be displayed should account for the following:

- Mission areas--the mission/tactical environment/relative geometry in the pertinent display modes
- Target data--
    - target contact--(onset/attenuation/disappearance of targets as a function of range and other pertinent factors)
    - tracks, differentiation of target classes (e.g., EW emitter types), positions in the environment
    - range/bearing information, aspect, depth/altitude
- Own-ship and support units--
    - identity, position and tracks, movement
- Indication of the system state/simulator mode of operation and the present phase or point in the mission
- Status of events (e.g., indication of jammer activation, chaff activation)
- Performance information on each student (error indications, scoring information) in the pertinent display modes and formats
- Indication of the student control/tactical actions and consequences of student actions, for monitor and control of training (e.g., range scale settings, sector selection, selection of operating modes such as MAD, deployment of sonobuoys)
- Indication of student detection/identification of targets once displayed (event and time of event)
- Indication of instructor actions once initiated/controlled over time
- Information for manual control functions (e.g., position, heading, altitude/depth and speed information for "flying" an aircraft or controlling a submarine target)

2.8.4.2 Display Techniques. Decisions on primary display techniques (media and mechanization) for monitor, evaluation, and control of training are based on a correlation of the information requirements for the system and the characteristics of classes of display. The choices range across the following:

- Repeater displays (reproductions of trainee displays)
- Event on/off indications (e.g., indicators depicting an out-of-tolerance event, the trainee mode selection, or instructor insertion of an event (control/display integration))
- Plotting boards (mechanized)
- Computer generated displays--synthesized multi-format/integrated displays (e.g., Cathode Ray Tube display of alpha-numeric/pictorial-situational information)

2.8.4.2.1 Criteria for Defining Primary Display Requirements. Decisions on primary display techniques and display modes/format requirements should consider the following criteria.

- Information handling capability (amount, types, rapidity of change, number of trainees under control)
- Multi-format requirements, high density information display, information integration (alpha-numeric and situational/graphic display requirements involving discrete event and overall situation displays; continuous alpha-numeric error readouts)
- Rapid mode changes for monitoring, control and evaluation, requirements for monitor and control of more than one trainee sequentially
- Display flexibility (with relevant controls)
    - mission/geographic areas
    - scale depictions
    - information classes
    - display modes
    - coding of displayed information
- Accuracy, reliability and registration (information alignment) of the visual displays

- Expansion capability (for future display requirements)
- Visual factors (acuity, luminance, refresh rate/flicker, contrast sensitivity, resolution, clutter)

2.8.4.2.2 Ancillary Display Requirements. Requirements are also specified for those displays not primarily involved in the instructional process but which are necessary to training system operation (e.g., mission timers, system status displays, etc.).

2.8.5 Instructor Console Controls. To achieve full use of the instructional capability, a number of classes of controls are required to operate the training device and to enable the shaping of behavior in the trainee compartment(s). The control classes include the following:

- Device operation--start, halt, reset, override.
- Means for selecting displays and display modes (multi-format displays).
- Means for controlling vehicles (e.g., controls for "flying" an aircraft, steering a target submarine).
- Means for positioning units in the mission, both initially at problem start and during the mission.
- Means for inserting and manipulating targets (e.g., time and position of entering targets, repositioning of targets, control of range between targets or between own-vehicle and targets).
- Means for direct access to the device computation system (manual input controls such as keyboard, light pen).
- Means for inserting new error tolerance into computer (Δ error) when trainee exceeds current programed error limits.
- Environment (media) controls.
- Communications controls.
- Means for simulating failures/emergencies.

- Means for inserting scenario/mission events during an exercise for both non-programed and preprogramed exercises.

- Means for eliminating defined programed events (for example, in preprogramed scenarios, "erasing" an airborne interceptor threat in an EW defensive mission that is scheduled to appear but is not desired at this time because of the training strategy being developed for a particular student).

2.8.5.1 Selection of Controls. Decisions on the selection of controls for operating the instructor station and controlling the training are based on the following criteria:

- Display-control compatibility (compatibility with tabular and graphic formats).
- The amount and types of information and speed requirements in information reception and transmission.
- Number and size required to avoid clutter, ambiguity and needless redundancy because of the potential for error in usage.
- Ease of operation, particularly where instructor to student ratios are high.
- Efficiency of panel space usage.

Instructor console controls can be grouped according to the functions performed (obtained from the instructor functions analysis) which in turn affects the choices incontrol selection.

2.8.5.1.1 Mission/Instructional Controls--(on-line). These are the major groups of controls used for structuring and controlling training during the exercise, and range from switches through control-display indicators to manual input devices. In multi-man training systems where fast access to much information in multi-formats is necessary, the selection of manual input controls with compatible displays is an important decision for training management. The alternatives available in the selection of controls include the following:

- Switch/indicator array (engraved legends)
- Digit keyset

- Alpha-numeric keyboard
- Joystick (cursor symbol positioner)
- Trackball (cursor symbol positioner)
- x-y multi-gain push buttons (cursor symbol positioners)
- light pen (or light gun)

2.8.5.1.2 Scenario Modification--(off-line). These are the controls for modifying or generating new scenarios when preprogramed training exercises are employed. For the manual mode, the pertinent controls are those for the efficient setup of the initial conditions for an exercise.

2.8.5.1.3 Ancillary and Power Supply. These are the controls associated with the operation of the training device, e.g., power to instructor console, mission initiation (control for starting the mission scenario), mission program generation (control for initiation (off-line) of a new mission, e.g., to call up a page of CRT information in order to select desired parameters for a new mission scenario), emergency stop, lamp test, etc.

2.8.5.1.4 Communications. These are standard controls, most often, replicas of existing operational equipment for two-way communications with a student(s) (individual or group); with a remote instructor(s); with a device operator and other associated personnel.

2.8.6 Monitor and Control of Training (during the training exercise). To achieve the training purpose and the training objectives for the system, the characteristics of the instructional capability must also be specified. The instructor must be provided displays of necessary performance information on each student and the controls and communications necessary to develop a training strategy for each student. The options to provide the instructor (via hardware) for enhancing the training value of the device include the following:

- Provide monitoring and control of performance via error displays at the console. This information is used in judgments for continuing the mission as preprogramed (automated scenarios) or as planned (manual scenario setup); or for remedial action (changes to preprogramed mission or changes in event insertion via script). Verbal communication capability with trainee is required throughout the training exercise. An example of a student performance information display is provided in Figure 13. This is a sample of a basic CRT page format showing a recommended positioning of the displayed information.

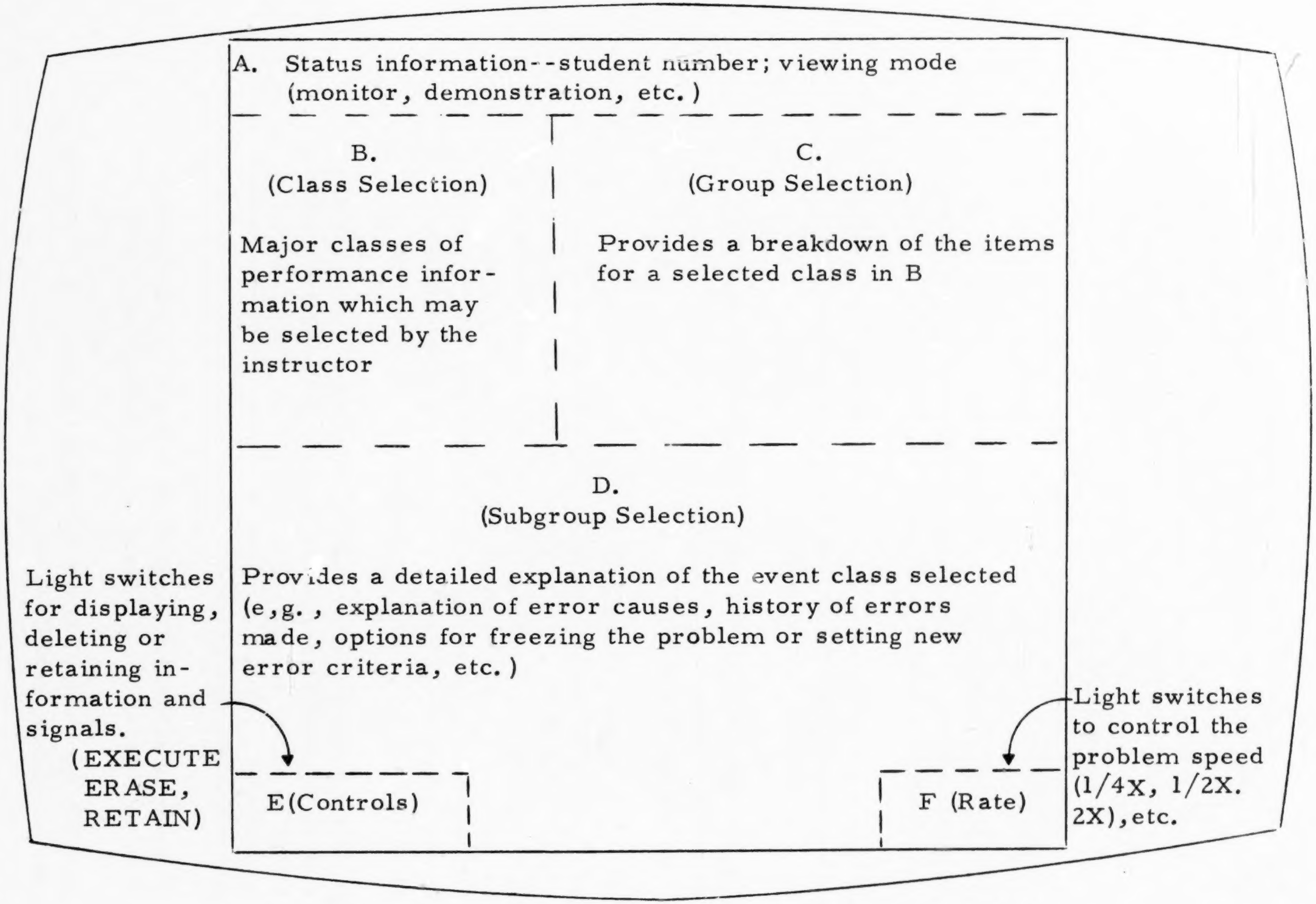

A. Status information--student number; viewing mode (monitor, demonstration, etc.)
B. (Class Selection)
Major classes of performance information which may be selected by the instructor
C. (Group Selection)
Provides a breakdown of the items for a selected class in B
D. (Subgroup Selection)
Provides a detailed explanation of the event class selected (e,g., explanation of error causes, history of errors made, options for freezing the problem or setting new error criteria, etc.)
Light switches for displaying, deleting or retaining information and signals. (EXECUTE ERASE, RETAIN)
E(Controls)
F (Rate)
Light switches to control the problem speed (1/4X, 1/2X. 2X), etc.

Figure 13. Basic Layout and Placement of Information for a CRT Page Format (Alpha-numeric).

In this case, the instructor, by means of a light pen control, is able to call up various classes of information (alpha-numeric) on a given student. A sample of a CRT page format of alpha-numeric information is shown in Figure 14. A situational (pictorial) display format is also desirable (see Figure 15). The information in these figures refers to electronic warfare simulation. An example of a combined graphic and alpha-numeric CRT format is shown in Figure 16 for a proposed multi-student navigational trainer (Bark, et al, 1969).

- Provide demonstration mode capability for any or all students during briefing and also enroute in the exercise (problem halt or with problem underway).
- Capability for problem halt and recycling of a portion of the mission to reinstruct an erring student in a defined portion just completed.
- Capability, in preprogramed scenarios, to manually override any event entry when it is in position for entering the mission.
- Provide, in preprogramed scenarios, options to advance individual students at their best rate of progression (i.e., based on an automated monitoring and scoring capability). This can be accomplished for those who have demonstrated performance exceeding scenario requirements for a specific mission or sequence of training. Additional events and malfunctions (in type and frequency) can be inserted.
- Provide a capability to call up records of automatically scored student performance for the purpose of critique, either on-the-spot during a mission or after mission completion, and for detailed hard copy of performance for school record keeping.
- Provide problem halt capability for any or all students for demonstration, guidance or administrative hold.
- Provide for control of the speed of the training scenario/problem (slow/real/fast time).

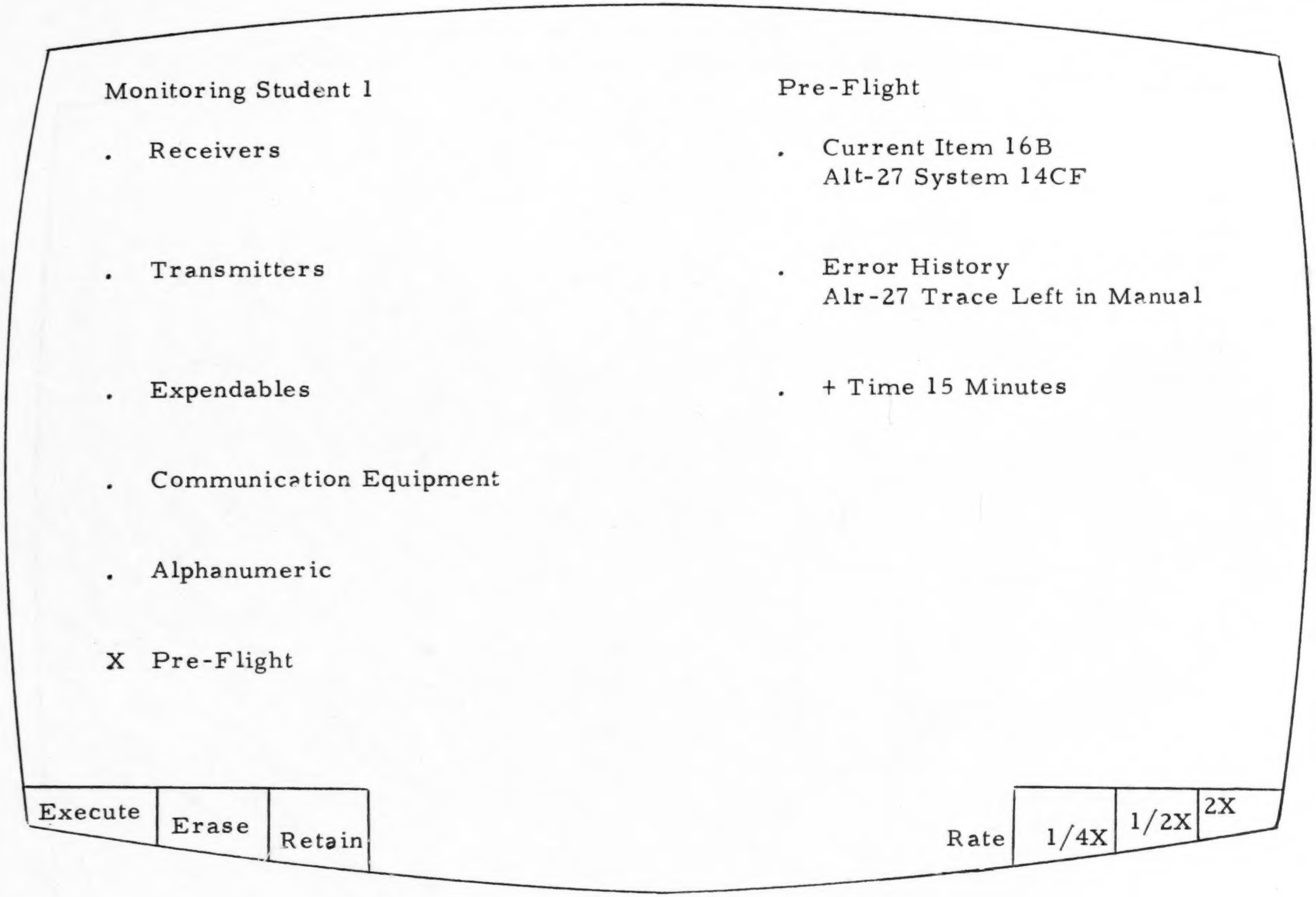

Monitoring Student 1
. Receivers
. Transmitters
. Expendables
. Communication Equipment
. Alphanumeric
X Pre-Flight
Pre-Flight
. Current Item 16B
Alt-27 System 14CF
. Error History
Alr-27 Trace Left in Manual
. + Time 15 Minutes
Execute
Erase
Retain
Rate
1/4X
1/2X
2X

Figure 14. CRT Page Format of Alpha-numeric Information
(the example is for error analysis in pre-flight setup).

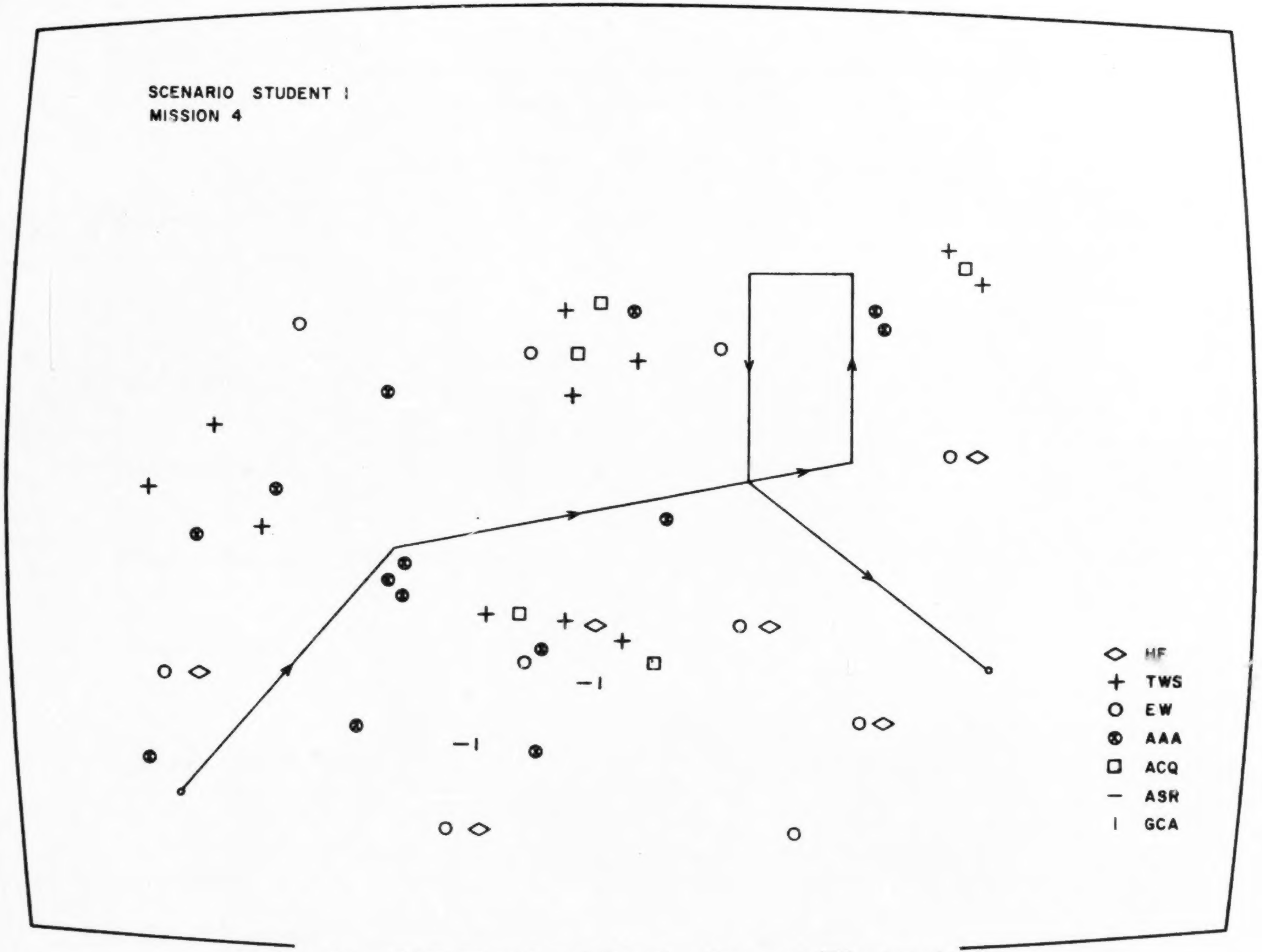

SCENARIO STUDENT 1
MISSION 4
◇ HF
+ TWS
○ EW
⊗ AAA
□ ACQ
— ASR
I GCA

Figure 15. CRT Situational Display Format (Electronic Warfare Mission Scenario).

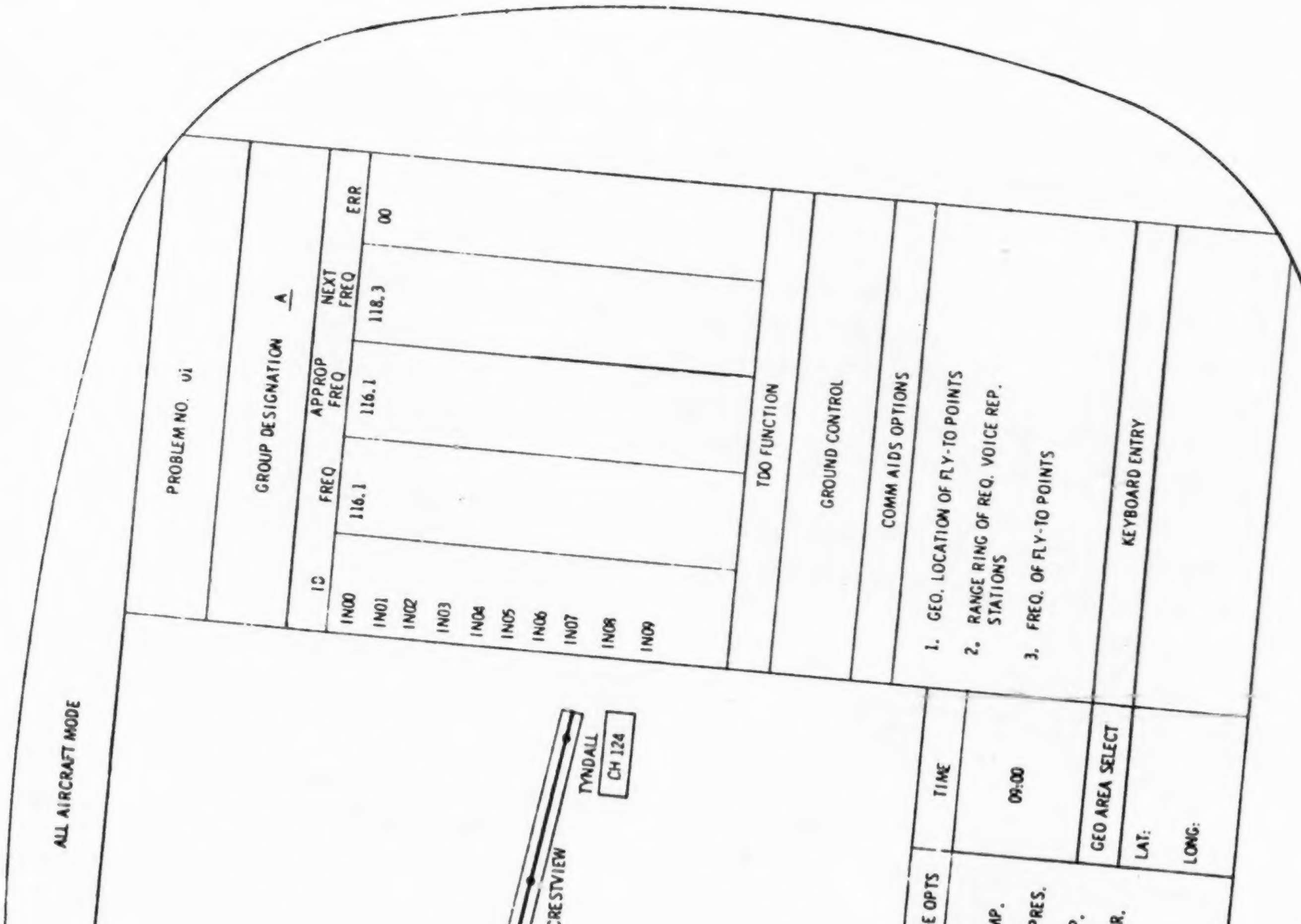

ALL AIRCRAFT MODE
PROBLEM NO. 01
GROUP DESIGNATION A
ID
FREQ
APPROP FREQ
NEXT FREQ
ERR
IN00
IN01
IN02
IN03
IN04
IN05
IN06
IN07
IN08
IN09
116.1
116.1
118.3
00
TDO FUNCTION
GROUND CONTROL
COMM AIDS OPTIONS
1. GEO. LOCATION OF FLY-TO POINTS
2. RANGE RING OF REQ. VOICE REP. STATIONS
3. FREQ. OF FLY-TO POINTS
KEYBOARD ENTRY
NEW ORLEANS
113.2
CH 79
KEESLER
MOBILE
CH 75
FSS
CRESTVIEW
TYNDALL
CH 124
EQUIP MALF
LIST
EQUIP AVAIL
LIST
NAV AID OPTS
TYPE OF STATION
LOCATION
FREQUENCY
OPERATION
OVERRIDE OPTS
ENVIRON
1. AIR TEMP.
2. BARO. PRES.
3. WIND SP.
4. WIND DIR.
KOR
TIME
09:00
GEO AREA SELECT
LAT:
LONG:

Figure 16. Combined Graphic and Alpha-numeric CRT Format (from Bark, et al 1969)

2.8.7 Pre-mission Requirements. The hardware implications in instructor pre-mission activities involve the following:

- System confidence checks.
- Setup of initial conditions for an exercise in non-automated systems (i.e., manual insertion by the instructor).
- Capability for the selection of preprogramed mission scenarios in automated systems, also, the capability (off-line) to modify an existing scenario or generate an entirely new scenario as training objectives are modified or new training requirements emerge.
- Capability for in-station briefing, as required, including demonstration utilizing trainee compartment displays.

2.8.8 Post-mission Requirements. The hardware implications in instructor post-mission activities involve the following:

- Capability for recycling the system when automated preprogramed scenarios are used, or for shutting down the device.
- Capability to call up hard copy printouts of student performance indications for on-line critique (format and content) and for school record keeping (format and content for off-line analysis).
- Hardware for providing mission critique in the trainee station(s).
- Special equipment for critique required in the team training or multiple student contexts (e.g., visual projection displays, audio and audio/video recording, etc., in a central critiquing area for the reconstruction of the mission just accomplished).

2.8.9 Measurement System. Understanding, modifying and predicting human behavior depend upon measurement operations. Knowledge about the outputs of performance provides a basis for assessing the effects of training and for predicting performance under future conditions. In fact, performance measurement is the bridge between the trainee outputs and the information requirements at the instructor station. Thus, measurement requirements involving the specification of what and how to measure, the software programing, and the utilization of display and recording equipment must be carefully evaluated.

Assuming the decision has been made to provide a measurement of performance capability in the device, an effort is undertaken to determine the scoring requirements and means for implementing the scoring capability. The human factors inputs in developing the measurement capability will be described here for the most demanding case, that of an automated measurement system involving computer monitoring, scoring and evaluation. For training devices in which automatic scoring and evaluation, and data recording are not warranted, the inputs can be selected as needed from the following discussion.

The development of any proficiency measurement system is a difficult undertaking involving technically complex issues. A number of requirements must be satisfied, and measurement errors accrue that are directly attributable to failures in satisfying these requirements. The more prominent among these relate to reliability, validity, behavioral sampling practices, the selection of measures, the characteristics of the measures (objective vs. subjective, overall vs. diagnostic, individual vs. team), levels of measurement (i.e., types of measurement scales) and mathematical and statistical operations. These issues have been examined in depth in a number of substantial documents. It is sufficient for our purposes to call the reader's attention to these. Representative sources from this large store include the work of: Glaser and Klaus (1962); Lindquist (1951); Buckhout and Cotterman (1963); Smode, Gruber and Ely (1962); Ericksen (1952); Krumm and Farina (1962); and Greer, Smith and Hatfield (1962).

Assuming the above mentioned considerations, the development of the measurement capability for a training device involves the accomplishment of a series of logical interrelated steps. This sequence of operations is described next.

2.8.9.1 Identify the Important and Critical Tasks. Based on the system and job analyses, the requirement is to break down individual, subteam, and team tasks into manageable units of performance that are observable and quantifiable. Decisions must be made in selecting more discrete units of behavior and more comprehensive segments of performance. The desired product is a list of things worthy of measurement.

An outline of the task structure is the necessary basis for the development of measurement classes and associated scores. What is needed here has already been accomplished in Phase 3 and it is mostly a matter of correlating skills and knowledge requirements with scores that are relevant and obtainable. Additional insights may be gained by means ranging from discussions with operational personnel knowledgeable in the type of training contemplated to flow charts of the computer operations involved in monitoring student activity.

Using the electronic warfare training system example cited earlier, the initial cut at task structure needed for organizing the measurement requirements can be described as follows:

- Procedures following--heavy emphasis on switch positioning throughout the mission scenario (setting up equipments, configuring equipments to obtain desired parameters, making mode changes, selecting bands, peaking/optimizing signals, etc.)
- Signal detection--(visual, aural)
- Signal recognition and pattern comparison--display interpretation and recognition of signal signatures
- Decision making--decision options within the bounds of EW doctrine, threat assessment in terms of priority search and threat priority
- Communications
- Log keeping
- Crew coordination

2.8.9.2 Quantify the Performance Elements and Select Measures Appropriate to the Behavior to be Evaluated. Quantifying behavior involves the consideration of the missions performed in the system and the selection of parameters which are useful and can be obtained efficiently. A variety of measures are available for describing specific behavioral sequences in performance. The selection of measures pertinent to the purpose of training should include both diagnostic indicants of performance as well as system output measures.

As an aid to planning, an organization of basic types of measures that may be used in combination is provided in Table 8. These classes of measures are graded on a quantitative-qualitative continuum with precise quantities (time, accuracy, frequency) at one end and more qualitative interpretations at the other end. Each class includes a variety of subgroups and specific measures (Smode, Gruber and Ely, 1962; SAE, 1968).

The selection of measures for the measurement system must reflect the following:

- Both objective and subjective measures are desired. There are performances that do not lend themselves to quantification or objective scoring. In fact, larger, relatively richer segments of performance are best assessed by direct observation (e.g., team coordination).

- Both diagnostic measures (indicants of weakness, strength in skills and specific performances within the general capability) and system-terminal measures (indicants of system output) are required.

- Measures must consider the interactive effects of man and equipment. The measurement requirements are highly specific to each system in terms of mission requirements and the equipments operated. The classification of measures in Table 8 provides assistance in identifying the types of measures meaningful in any system context. The measures selected need then to be put in terms specific to the contemplated training system.

- The use of measures describing infrequently occurring events is desirable. Performance on improbable events (involving safety/hazard, emergencies and malfunctions) provides data of value for training.

Two specific examples are provided concerning the selection of appropriate measures. The first example concerns the airborne EW system cited earlier. For the basic EW defensive mission, the computer scorable measurement classes and applicable scores are organized within segments of flight in the mission cycle. The measurement classes concern the following:

- Switch setup positions
- Equipment preset (bands/frequencies requirements)
- Switch setup for the signal analysis
- Threat assessment
- Switch setup for jamming
- Initiation of jamming
- Use of expendables
- Threat priority
- Environment coverage
- Evasive maneuvers
- Communications
- Switch shutdown positions

TABLE 8. A CLASSIFICATION OF MEASURES

TIME: Measures dealing with time periods in production of performance.

1. Time to Initiate an Activity from the Onset of a Signal or Related Events
    - Time to perceive event
    - Reaction time
    - Time to initiate a correction
    - Time to initiate a subsequent activity (following completion of a prior activity)
    - Time to initiate a course of action
    - Time to detect trend of multiple related events
2. Time to Complete an Initiated Activity
    - Time to acquire, to lock-on, to identify
    - Time to complete single message
    - Time to complete a computational problem
    - Time to make an adjustment/manipulation/control positioning
    - Time to reach a criterion
3. Overall Time from Signal Onset to Activity Completion
    - Percent time-on-target
    - Time spent in an activity (communicating, repairing, computing, etc.)
    - Time to complete a sequence of activities
    - Build-up of time (cue length)
4. Distribution of Part Task Times in Completing an Activity
    - Time-sharing among events

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TABLE 8. A CLASSIFICATION OF MEASURES (Continued)

ACCURACY: Measures dealing with the correctness and adequacy of production of performance.

1. Correctness of Observation or Perception (Discrete/sequential)

   - Accuracy in identifying display readout
   - Accuracy in identifying extra-cockpit objects (environment, ground terrain, celestial navigation objects)
   - Accuracy in estimating distance, direction, speed
   - Time estimating accuracy
   - Detection of a trend based on multiple related events
   - Detection of change in presence of noise
   - Correctness of observation sequence

2. Correctness of Response or Output

   - Accuracy in control positioning (pressures, direction, amplitude rate, and duration)
   - Accuracy of in-flight maneuvers
   - Accuracy of retrofire maneuvers
   - Accuracy of intercept
   - Computing accuracy
   - Selection of action from among alternatives
   - Correct symbol usage
   - Accuracy in spatial positioning (navigation)
   - Accuracy in weapon delivery
   - Accuracy in landing

TABLE 8. A CLASSIFICATION OF MEASURES (Continued)

3. Error Magnitude

    Error amplitude measures

    Error frequency measures

    Error distance (circular or linear)

4. Correctness of Response Sequence

    Sequence of response

    Sequential-manipulative accuracy (serial response, one activity; coordinated response with several controls)

5. Adequacy of Probability Estimation (Relative to an 'Ideal Observer')

    Accuracy in using unreliable information

    Recognition of out-of-tolerance condition

FREQUENCY OF OCCURRENCE: Measures dealing with the rate of repetition of behavior.

1. Number of Responses Per Activity or Interval

    Number of actions made per unit

    Number of communications per activity or interval

    Number of adjustments to maintain in-tolerance (number of checks, replacements, problems solved)

    Number of interactions with other members

    Number of gross/significant errors per unit

2. Number of Defined Consequences of Performance Per Activity

    Number of out-of-tolerance conditions

TABLE 8. A CLASSIFICATION OF MEASURES (Continued)

3. Number of Observing or Data-Gathering Responses
    - Number of requests for information
    - Number of interrogations/observations made
    - Number of discrete recordings/reportings made

AMOUNT ACHIEVED OR ACCOMPLISHED: Measures dealing with the amount of output or accomplishment in performance.

1. Response Magnitude or Quantity Achieved
    - Degree or proportion of success (intercepts, information collection, weapon delivery, rescue, landing, etc.)
    - Cumulative response output
    - Written test of knowledge (scores)
2. Man-Machine System Achievement
    - Attainment of training objectives
    - Assessment of "merit" in performance (influenced by man-machine interactions)

CONSUMPTION OR QUANTITY USED: Measures dealing with resources expended in performance in terms of standard references.

1. Resources Consumed Per Activity
    - Fuel-energy conservation
    - Units consumed in activity accomplishment
2. Resources Consumed Per Time
    - Rate of consumption

TABLE 8. A CLASSIFICATION OF MEASURES (Continued)

BEHAVIOR CATEGORIZATION BY OBSERVERS:	Measures dealing with classifying more complete behaviors into operationally defined subjective categories. Observations are placed into discrete classes on a continuum for the event observed.

1. Classifying Activities or Handling of Events
    - Impromptu response invention (improvising)
    - Communication effectiveness
    - Redundant communications
    - Emotional content of communication
    - Priority assignment to an activity or among activities
2. Overall Judgments of Performance
    - Coordination of effort/movement
    - Procedural synchronization of action
    - Relevance of response
    - Substantive content of communication
    - Intelligibility of voice report
    - Use made of available references, job information, test equipment
    - Visual-perceptual orientation
    - Crew cohesiveness
    - Quality of checks (fault location)
    - Use made of performance information available from symptoms/checks/errors

TABLE 8. A CLASSIFICATION OF MEASURES (Continued)

Adequacy/goodness of behavior (gross rating of a complex performance)

Adherence to safety procedures (handling of equipment)

CONDITION OR STATE OF THE INDIVIDUAL IN RELATION TO THE TASK: Measures dealing directly with the state of the individual which describe behavior and/or results of acts that have occurred.

1. Description of Behavior at Prescribed Times

Response perseveration

Anticipation of probable events

Alertness to events

2. Description of Condition

Behavioral intactness of individuals/crew

Physiological condition of individual/crew (life support) (by means of attachment on body surface or equipment near the body: electrocardiogram, electroencephalogram, temperature, galvanic skin response, sound at ear drum, etc.)

3. Self Report of Experience

Report illusory phenomena (apparent movements; quality and duration of illusory movements)

Protocols of experience

Table 9 identifies the scores obtainable (via computer software programs) for the defined classes of measures. Where other mission requirements are distinct from the selected mission the additional measurement classes are incorporated in the listing. Thus, in the same EW example, the basic reconnaissance mission (ELINT) requires measurement classes in addition to those shown for the defensive mission. These include: signal setup for DF bearing, recording, analysis of signal, subsequent DF bearings, priority search, and general area reconnaissance.

The second example involves an Operational Flight Trainer wherein measurement is concerned with flight and navigational skills. In this instance, computer programing provides a record (hard copy printout) of selected parameters of defined maneuvers when any given parameter exceeds a preset range of parameter deviation (the instructor is able to preprogram the tolerance limits for each parameter). Various types of measures are needed to describe the performances selected for assessment. These defined measures are correlated with appropriate flight parameters, and serve to assist the instructor in selecting only those parameters (for display) which have diagnostic relevance to the performance being examined. Table 10 identifies the parameters available to the instructor for measuring defined aspects of trainee performance.

2.8.9.3 Establish Performance Criteria. Standards of performance are required if the proficiency measures are to predict on-the-job performance. Standards (predetermined norms defining acceptable tolerances for performance) provide the basis for the comparison and evaluation of student performances and hence relate importantly to training strategy.

Various means are available for achieving these criteria. Standards can be set for a number of performances from the rational analysis of the system and task structure. For certain behaviors, adequacy of performance may be differentiated on the basis of time to perform. Reaction time may be critical or error response may be detrimental unless corrected (assuming adequate feedback of performance information) within a short time period after the error response. In other instances, emphasis may be placed on quality and precision of response or on the integration of activities that indicate an ability to cope with a range of unforeseen contingencies.

Another approach to the development of interim standards involves the use of the a priori model of system and vehicle performance which is developed during the design phases of the operational system. The relationships between components as specified in the model can at times be translated into terms allowing a quantitative expression of performance levels required for successful performance.

TABLE 9. BASIC EW DEFENSIVE MISSION MEASURES AND SCORES

Mission Phase	Measure	Scores
Flight planning	N/A	N/A
Pre-flight setup	Switch setup positions	Sequence of switch positions (checklist format)
		Switch setting error
		Omission of switch setting
		Malfunction correction
		Communications (position of channel switches)
	Equipment preset (bands/frequencies requirements)	
		Switch positions in equipment preset
Emitter environment	Switch setup in signal analysis	
		Switch position in detection (signal to be countered)
		Time to detect
		Failure to detect
		Cue buildup (onset of signal to action)
		Switch position in identification (wrong emitter)
		Time to identify type of signal

TABLE 9. BASIC EW DEFENSIVE MISSION MEASURES AND SCORES (Continued)

Mission Phase	Measure	Scores
		Mode of operation in switch settings receiver transmitter expendables
		Malfunction correction sequences
		Total number of signals countered
	Threat assessment	Switch positions
		Time of handling threat
	Setup for jamming	Switch positions on jamming systems
		Time to set up
	Initiation of jamming	Time at which jamming is initiated
		Time during which jamming is effective
	Use of expendables	Switch positions for selecting expendable dispensing programs
		Time to initiate
		Time at which expendable program is terminated
		Failure to release expendables
		Maintenance of minimum stores level

TABLE 9. BASIC EW DEFENSIVE MISSION MEASURES AND SCORES (Continued)

Mission Phase	Measure	Scores
	Threat priority	Signals attended to in time
		Switch positions
		Time of handling new, higher priority threat (cue buildup)
	Environment coverage	Signals and/or bands covered
		Jammer refinement switch settings initial subsequent
		Number of jammers on individual signals and/or bands
	Evasive maneuvers	Maneuver selection
		Time of initiation
	Communications	Switch positions on interphone and communications equipments
Post-flight shutdown	Switch shutdown positions	Sequence of switch positions
		Switch setting error
		Communications (position of channel switches)

TABLE 10. PARAMETERS RELEVANT TO MEASURING FLIGHT AND NAVIGATIONAL SKILLS IN AN OPERATIONAL FLIGHT TRAINER

Measure	Parameters (Deviation Recording)
1. Aircraft attitude/position geometry	Heading, altitude, air speed, pitch angle, roll angle, flight path, flight path deviation, approach slope, approach slope deviation.
2. Force/rate	G-loading, vertical velocity, turn rate, longitudinal stick rate, lateral stick rate, rudder rate, pitch rate, roll rate, yaw rate.
3. Position of aircraft controls	Longitudinal stick position, lateral stick position, rudder position, throttle position.
4. Discrete event activation	Flaps, landing gear, speed brakes, thrust attenuator, elevator tab up, elevator tab down, canopy controls.
5. Time	Time to initiate an event or sequence from onset of signal, time to complete an initiated activity, overall time from signal onset to activity completion.
6. Instrument readings	Engine instruments, RPM.

For more complex performances, the criteria should be based on empirical evidence. Ideally, experiments and actual data collection in the operational setting are desired for establishing the standards. Practically, however, expert opinions are used to establish criteria for successful performance. This intuitive approach is good where standards do not exist or have not been quantified. Interim criteria can be developed in this manner since subject matter experts can provide solid guidance in the development of standards. The weakness of this approach is that the biases of these people may influence the standards set.

Where a scoring capability exists, obtaining repeated scores will allow the development of criteria. For example, if an actual simulation of the system is set up in the course of its development, data can be obtained to identify required performance levels.

The error criteria should be flexible to account for stage of training, and modifiable to enable change as experience with the training program is gained. Thus, initially, tolerances are set intuitively based on previous experience and judgment and are refined as a data base accumulates with experience in the use of the system or as training objectives are modified.

In automated training sequences (e.g., preprogramed scenarios that may be modified by the instructor during an exercise) consideration must be given to the capability for modifying the computer scoring criteria in the software programs. For example, an "error alert" mode is a special case of evaluation whereby the computer halts the problem when a trainee exceeds the permissable error envelop in terms of the preset scoring criteria established for a particular mission or stage of training. The requirement is to set in new error criteria to establish the next error alert (computer halt) level. This can be accomplished via CRT display (e.g., page(s) of alpha-numeric information for error analysis) and appropriate controls (e.g., keyboard, light pen). A design decision concerns the provision of this capability at the instructor console. The instructor may override the computer halt or accept the halt with or without inserting new evaluation criteria, in order to implement decisions on training strategy (e.g., to continue the exercise as briefed, to replay a portion of the just completed training segment for the purpose of reinstruction, or to provide demonstration to the student).

2.8.9.4 Determine Conditions Under Which to Measure Performance. Once the measurement requirements have been determined, the task conditions under which performance should be measured must be specified. As with the tasks themselves, the conditions under which performance is observed will necessarily represent a sampling of the anticipated real conditions. In selecting the sample of conditions that will prevail, the following two general rules should be considered:

Those conditions should be selected which are known (or suspected) to have the greater influence on performance.

Within those conditions selected, the extremes or limits anticipated should be included.

Task conditions are independent of what measures will be used (i.e., decide on what measurements are desired, then determine the conditions). The conditions of measurement, however, do influence when the measurements will be taken and in some instances how often the measures will be repeated. For example, when load conditions vary in a mission sequence, it may be appropriate to take measurements at selected points in order to indicate system status or performance at these times.

Emphasis must be placed on the standardization of test conditions and environments. Not only should measures be standard (used in similar ways with the same meaning by the personnel involved) but also, the general environment in which the measurement is to be taken should be standard. Adherence to this insures that measures will be strictly comparable from one student to another, from one team to another, and from one time to another.

Two types of variations in the conditions under which performance can be observed are apparent. These are, task conditions and environmental conditions. Measurement should be conducted under a variety of task loadings representative of those which may be or are encountered in operations. Task loading should be systematically manipulated to induce stress evoked by situations requiring unusual or complex decisions and emergency situations which give rise to additional task demands.

It is important also to conduct measurement under the more important environmental conditions. These include: acceleration forces, movement about axes, sound and vibration, temperature extremes, and the range of visual conditions. The selection should consider those that have importance to successful performance and will not endanger the safety of the individual. This sampling should include the extremes expected and also unusual conditions.

In order to provide the selected conditions in a uniform manner throughout training and measurement, design should provide for calibration of the simulated environment.

2.8.9.5 Data Handling and Display. Instrumentation is a key factor in the design of a measurement system and selecting the equipment array is a critical aspect. The display of student performance information and error information must consider:

a. The number and types of displays required

- Counters, timers and scalars (meters, CRTs) provide classes of measures describing frequency, time, accuracy, amplitude and amount.

- Computer driven, multi-format Cathode Ray Tube displays afford the greatest versatility for instructional control.

b. The display modes

- Both continuous performance error indications as well as discrete classes of performance information on-demand are required. CRT displays include both alpha-numeric and graphic page formats with associated selection controls (e.g. light pen, keyboard input devices).

- Computer generated error alert indication provides an automatic display of student error information when performance is out-of-tolerance for a defined error class.

2.8.9.6 Techniques for Recording Measurement Data. Computer programing is required to 1) monitor the critical aspects of student performance, 2) score all students objectively against standard parameters, 3) relay pertinent performance and error information to instructor console CRT displays, 4) deliver performance cues and performance information to displays at each student station (for example, augmented feedback of performance information in the form of alpha-numeric error indication), and 5) provide a record of performance for all students throughout each mission. Since the digital computer is capable of recording all time and event happenings, various records may be provided via hard copy printouts. The permanent records should be considered both for student critique and for school record keeping. Assuming hard copy records of performance are warranted, the design issue concerns what information is desired and their formats. In essence, three major classes of records are indicated:

- Time and event printouts for school record keeping and for developing a normative data base of performance information. (The concern for quality control in the production of trained personnel is a legitimate issue for design. Measurement data provide the basis for determining the quality level of the student population trained in the device.)

- Error printouts for mission critique (for use during and after exercise completion) in terms of error classes and error trends.

- Summary of error scoring--single page summary of errors per class, scores achieved, and total score for the exercise. A file may be kept of all student training exercises for the purpose of performance diagnosis.

Measures obtained during each exercise must be reduced into a meaningful usable form quickly in order to be employed for critique purposes. Thus, the data reduction system must be an integral part of the device computational capability and must be flexible to allow modifications in measures and standards as experience is gained with the measurement system.

2.8.9.7 Summary of Design Requirements for a Measurement System. Human factors design must consider the following in the development of an automated measurement system.

- Preprogramed mission scenarios graduated in exercise difficulty.

- Automated monitoring, evaluation and scoring capability.

- Definition of measures and standards.

- Definition of data collection techniques (see Figure 17).

- Displays of student performance and error information in all relevant modes and formats at the instructor station.

- Capability for recording student performance information.

- Capability for sampling student performances at specified points or intervals of time during an exercise.

- Capability for computing scores, combining of scores and the weighting of scores according to the established performance criteria.

- Hard copy printouts of student performance information for exercise critique and for school record keeping.

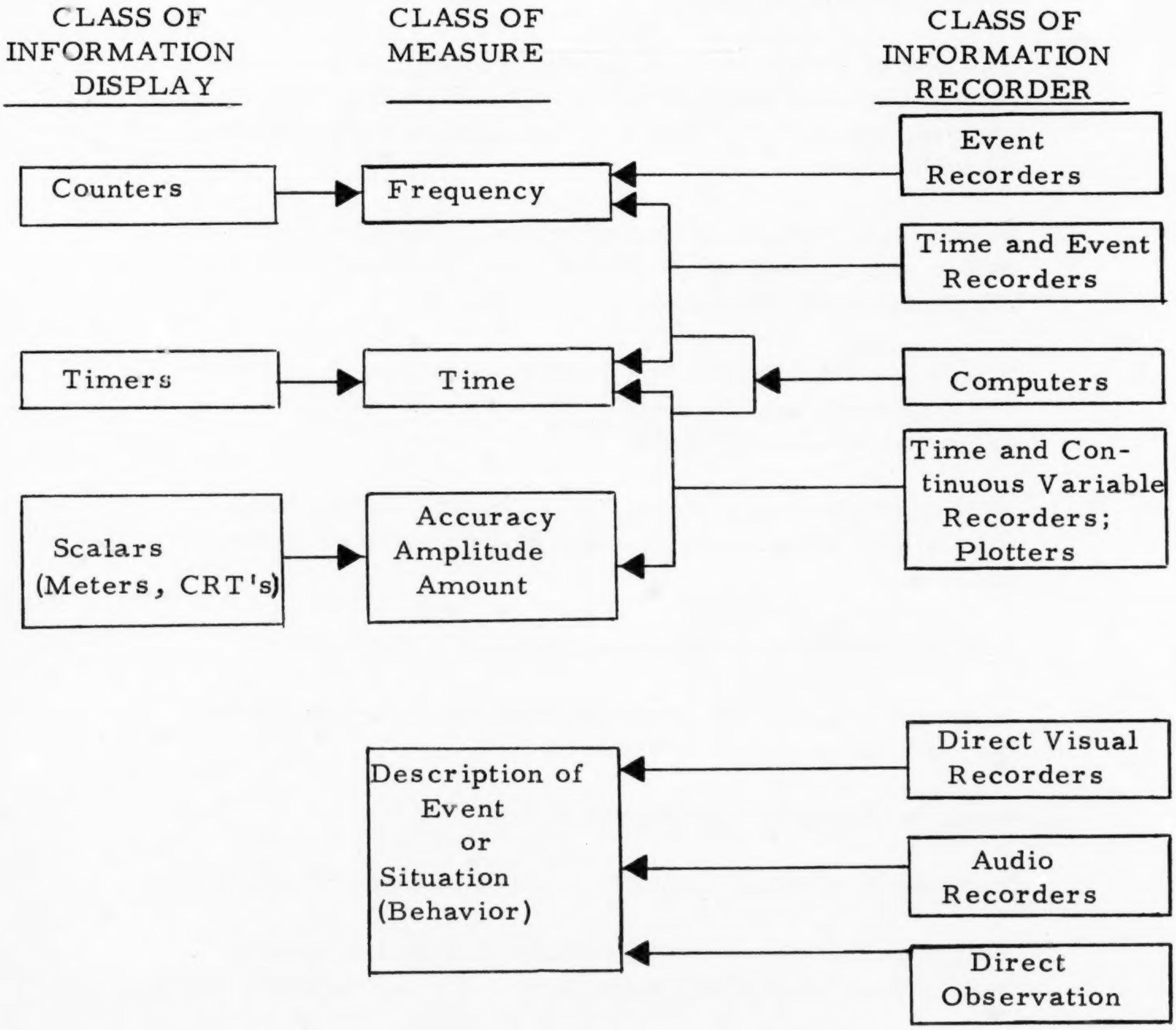

CLASS OF INFORMATION DISPLAY
CLASS OF MEASURE
CLASS OF INFORMATION RECORDER
Counters
Frequency
Event Recorders
Time and Event Recorders
Timers
Time
Computers
Time and Continuous Variable Recorders; Plotters
Scalars (Meters, CRT's)
Accuracy Amplitude Amount
Description of Event or Situation (Behavior)
Direct Visual Recorders
Audio Recorders
Direct Observation

Figure 17. Data Collection Techniques and the Classes of Measures they Provide.

2.8.10 Communications. The communications capability at the instructor console involves the following considerations.

- Extent of representation--replica of the operational system counterparts.
- The use of actual system communications components (e.g., controls and control panels, headsets, microphones, etc.) configured and operated as in the operational system.
- Instructor-student communications--selective communication with individual students, any combination of students, all students on interphone (as applicable).
- Status displays depicting (as applicable) which students are transmitting, receiving and what transmitters are being used; call lights.
- Ability to introduce static, background noises, background and simultaneous communications from other sources.
- Student-to-student communications (as applicable).
- Instructor to remote instructor(s)/operator communications, unavailable to students.
- Remote instructor to student links.
- Instructor monitoring of all communications channels.
- Ability to introduce extra-vehicle communications (e.g., messages from other units, ground control, etc.).

2.8.11 Overall Layout and Workplace Requirements. Instructor station layout should be accomplished in modularized components consistent with primary and secondary use requirements and with established human factors engineering design practices. Console configurations should reflect the groupings of display and controls to accommodate related functions and positioned in terms of frequency of use and criticality. The design must also consider flexibility in usage of the consoles, i.e., accommodating a single instructor or simultaneous use by more than one instructor. A general idea of desired layout groupings is shown in Figure 18.

Special design problems pertinent to a given training device under consideration must also be resolved. These center on issues arising from constraints in layout and workplace, due primarily to:

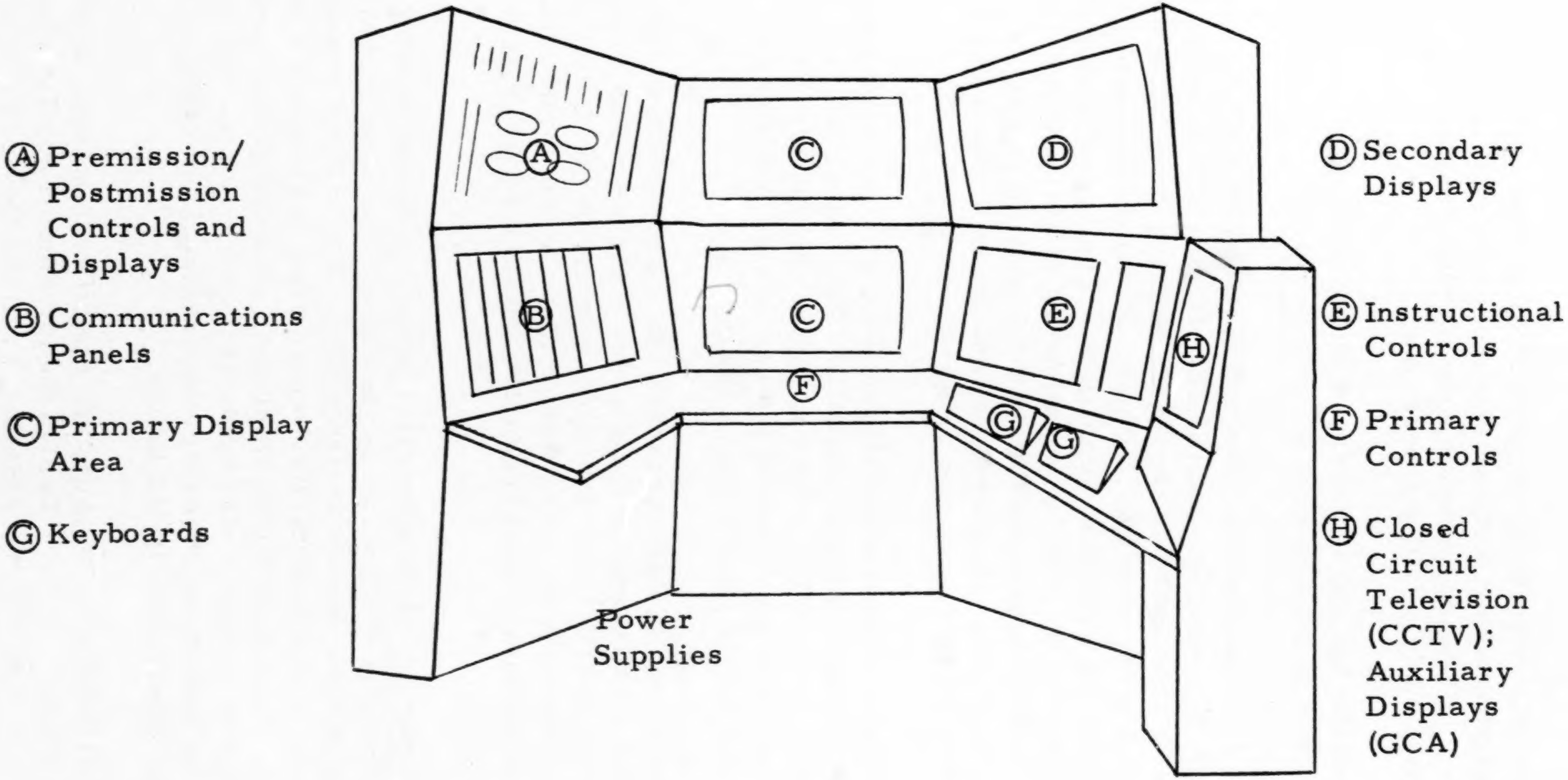

Ⓐ Premission/ Postmission Controls and Displays
Ⓑ Communications Panels
Ⓒ Primary Display Area
Ⓖ Keyboards
Ⓓ Secondary Displays
Ⓔ Instructional Controls
Ⓕ Primary Controls
Ⓗ Closed Circuit Television (CCTV); Auxiliary Displays (GCA)
Ⓐ
Ⓑ
Ⓒ
Ⓒ
Ⓓ
Ⓔ
Ⓕ
Ⓖ
Ⓖ
Ⓗ
Power Supplies

Figure 18. General Layout of Display and Control Groups in Instructor Station Design.

- Space limitations in room size or in dimensions (such as aboard a vehicle).
- Arrangements requiring integration of components (e.g., incorporating the instructor console(s) into a master briefing room which may involve problems in visibility during critique sessions.
- Requirements for the instructor to have unlimited visual access to all students as they perform.

A representative example of instructor station design is provided by the Synthetic Flight Training System (SFTS), Device 2B24 (Hundt, 1969). Figure 19 is an artist's conception of the SFTS showing the instructor station in relation to the four trainee cockpits. Figure 20 shows the layout of the controls and displays on the instructor consoles. The layout is founded on the intended primary use of the device in automatic mode, operated typically by one instructor with numerous visual displays available to several training personnel. The control and display functions on each panel are arranged with regard to expected frequency of use and criticality.

Another example of instructor station layout is the design proposed for a generalized submarine advanced casualty ship control training device (Lamb, Bertsche and Carey, 1970). This complex instructional facility shown in Figure 21, reflects good human factors design practices in layout and organization for achieving instructional efficiency.

2.8.12 Output. Functional design characteristics are specified for structuring, controlling and monitoring training at the instructor station complex. The range and extent of instructional functions are defined in terms of the display, control and communication requirements to achieve the capability for the management of training, commensurate with the purpose of the training system.

2.8.13 Human Engineering. It is sufficient for our purpose to state that the basic human engineering design standards and military specifications are applicable throughout the device design effort. We will not provide a discussion of this since it is a substantial design area possessing a well-developed body of literature with well-established principles and standards. A considerable number of military standards and specifications are in use today which specify the human engineering requirements for training device design. Pertinent documents are listed below.

MIL-D-22688(WEP) 1 November 1960	Military Specification Data, Avionics Design Requirements for Developing Aviation Training Devices

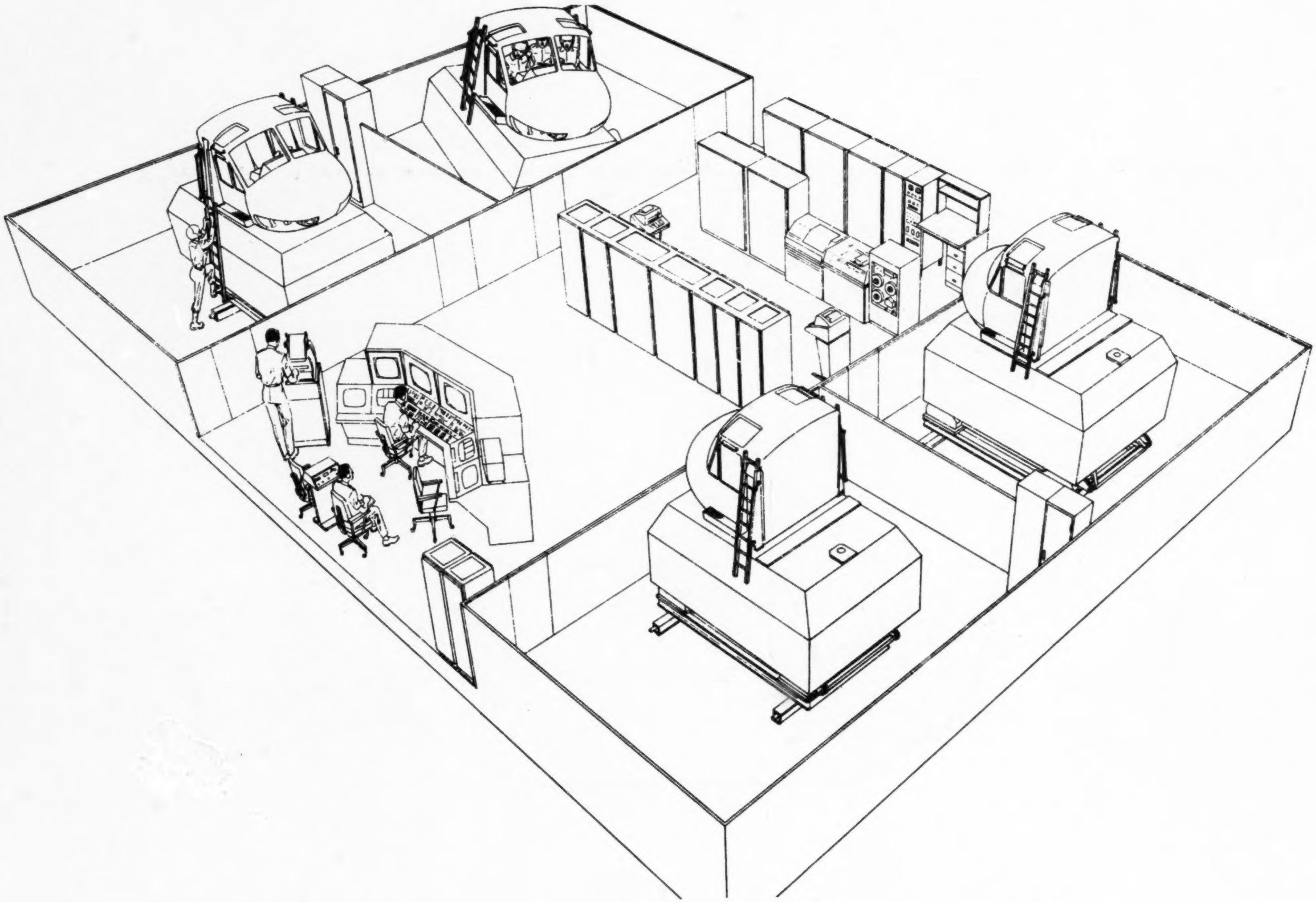


Figure 19. Artist's Conception of Synthetic Flight Training System, Device 2B24. (from Hundt, 1969)

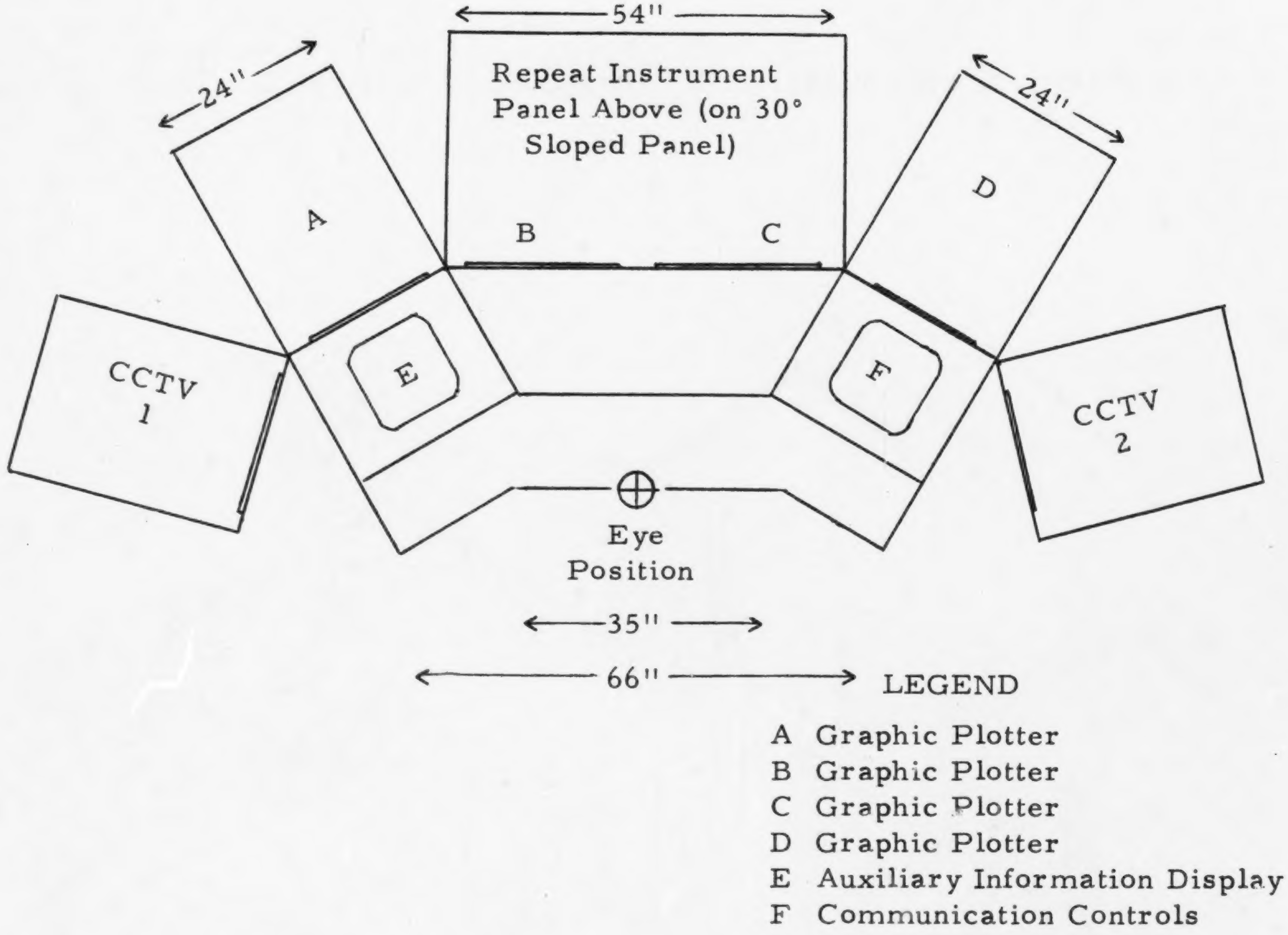
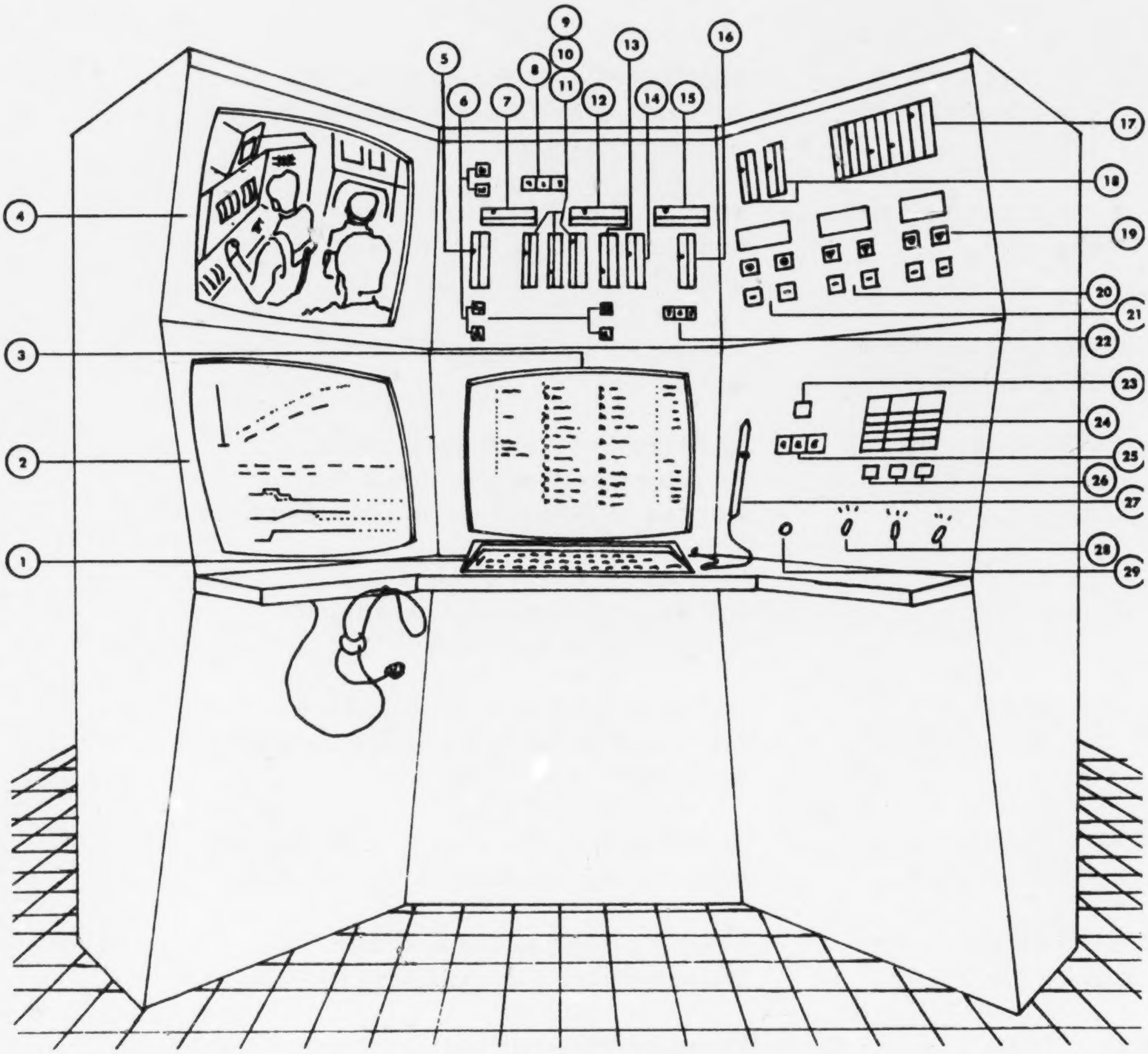

54"
24"
24"
Repeat Instrument Panel Above (on 30° Sloped Panel)
A
B
C
D
E
F
CCTV 1
CCTV 2
Eye Position
35"
66"
LEGEND
A Graphic Plotter
B Graphic Plotter
C Graphic Plotter
D Graphic Plotter
E Auxiliary Information Display
F Communication Controls

Figure 20. Viewing Angles and Dimensions of SFTS Instructor's Console (Plan View) (from Hundt, 1969)



1. Typewriter
2. Performance CRT display
3. Casualty control CRT display
4. T.V. monitor
5. Stern planes angle indicator
6. Planes mode indicators
7. Rudder angle indicator
8. Course digital read-out
9. Pitch angle indicator (left)
10. Depth indicator (center)
11. Depth rate indicator (right)
12. Speed indicator
13. Fairwater angle indicator
14. Depth to bottom indicator
15. Horizontal trim angle indicator
16. Buoyancy angle indicator
17. Air banks pressure indicators
18. DCT tank level indicators
19. NOR MBT (aft and fwd) valve position indicators
20. EMBT blow (aft and fwd) valve position indicators
21. Vents (fwd and aft) position indicators
22. Flooded water level indicator
23. Propulsion lost indicator
24. Hydraulic accumulators contents indicator
25. TAV – average steam temperature indicator
26. Pump on indicators – one each for lead, main, and vital
27. Light pen for use on CRT displays
28. Trainer controls
29. Emergency stop control button

Figure 21. Instructor Station Design Proposed for a Generalized Submarine Advanced Casualty Ship Control Trainer (from Lamb, Bertsche, and Carey, 1970).

MIL-D-23143(WEP) 15 December 1961	Military Specification Data, Technical Aircraft; For Design of Aviation Training Devices
MIL-D-26239A(USAF) 14 April 1961	Military Specification Data, Qualitative and Quantitative Personnel Requirements Information (QQPRI)
MIL-D-27382A(USAF) 31 January 1967	Military Specification Data, Training Equipment Technical
MIL-H-24148 (SHIPS) 15 November 1965	Military Specification Human Engineering Requirements for Bureau of Ships Systems and Equipment
MIL-H-27894A(USAF) 9 January 1963	Military Specification Human Engineering Requirements for Aerospace Systems and Equipment
MIL-H-46855 29 March 1968	Military Specification Human Engineering Requirements for Military Systems, Equipment and Facilities
MIL-H-81444(AS) 1 September 1966	Military Specification Human Factors Engineering Systems Analysis Data
MIL-T-6328H 9 September 1965	Military Specification Trainers, Maintenance, General Specification For
MIL-T-9213B(USAF) 28 June 1967	Military Specification Trainer, Flight Simulator, Aircraft, General Requirements For
MIL-T-23991C 1 June 1969	Military Specification Training Devices, Military: General Specification For
MIL-T-27474(USAF) 22 August 1960	Military Specification Training Equipment, Ground, General Requirements For
MIL-T-82335 (ONR/NTDC) 26 July 1965	Military Specification Trainers, Flight; General Specification For
MIL-T-82335A 11 April 1969	Military Specification Trainer, Fixed-Wing, Flight; General Specification For

MIL-T-82342B 2 January 1970	Military Specification Trainers, Cockpit Procedures, Aircraft; General Specification For
MIL-STD-850A 8 June 1967	Military Standard Aircrew Station Vision Requirements for Military Aircraft
MIL-STD-830A-2(USAF) 1 December 1964	Military Standard Human Engineering Design Criteria for Aerospace Systems and Equipment
MIL-STD-1472 9 February 1968	Military Standard Human Engineering Design Criteria for Military Systems, Equipment and Facilities
Air Force Systems Command AFSC Manual No. 80-3 15 April 1967	Handbook of Instructions for Aerospace Personnel Subsystem Design AFSCM 80-3

SECTION III

CONCEPTS AND DATA APPLICABLE TO THE DESIGN OF TRAINING SYSTEMS

This major section presents concepts and data which support the human factors effort in the design of synthetic training systems. It is based on a review of a substantial number of studies available in the literature that deals with various topics pertinent to the human factors design requirements articulated in Section II of this report. These researches cover a considerable range of content areas, employ diverse methods and are set in various laboratory, simulation, and field contexts. Our intent is straightforward: it is to examine this literature and determine from the array what data and concepts are serviceable in support of the human factors design effort.

Although a considerable body of information and data has accrued over many years of research and development, the unfortunate feature is that a data base has not evolved which provides firm guidelines for the human factors design of training devices. Quantitative design data are meager and spotty; some design areas possess little in the way of supportive data and require considerable applied research to acquire the information needed for design. This is particularly true of the recent innovative approaches developed for training. Much of the available data that is pertinent to design comes from laboratory research and we are beset by the traditional problems of correlating laboratory findings with the more complex requirements involved in synthetic training for real job situations. For the most part, laboratory tasks are simplified abstractions of the real job and generalizing from this is done with significant risks. As a result, considerable reliance in training device design has been placed on logical, intuitive considerations, and on empirical evidence.

Accordingly, our approach in this section is to assemble from the literature those data and concepts which possess utility for design (albeit differentially). Also, where evidence is significantly lacking, the data gaps are identified so that the discussions can be placed more nearly in perspective. Finally, researchable issues that are of priority for human factors design are identified.

Seven chapters are presented in this section. They deal with the following:

- Visual simulation
- Platform motion simulation
- Vehicle control requirements
- Information processing requirements
- Measurement system design
- Adaptive training strategies
- Deliberate departures from realism in design

3.1 VISUAL SIMULATION.[1]

This chapter sets out the considerations affecting the design of the visual environment in a training device.

The visual environment usually consists of some enclosure in which the trainee sits (for example, the cockpit of an aircraft) and a view to the outside world. In recent times the simulation of the outside world has become more usual, thereby increasing the realism and the training potential of training devices.

It does not follow, however, that the best trainer is necessarily the trainer with the most complete rendition of every aspect of the real-life visual environment. A trainer may be designed to teach only procedures; that is, the trainer would be a part-task trainer. A number of studies have indicated that trainers which are clearly incomplete in their simulation of the actuality, can be effective in producing an increment of performance in the trainee (Adams, et al, 1960; Boney and Prophet, 1963; Caro, et al, 1968; Dougherty, et al, 1957; Ellis, et al, 1969; Gagne and Foster, 1948).

Effective visual simulation for the purposes of training does not depend upon achieving a one-to-one copy. Rather, the aim is to achieve an adequate representation of the visual environment so that the experience is credible to the trainee, critical visual tasks are represented accurately, and all changes in performance (skill) brought about in the trainer have positive transfer to the actuality.

In fact, it may be asserted, it is not feasible to "recreate" the outside world in a simulator except when some portion of reality of a relatively simple kind is selected. When "recreation of reality" is regarded as the challenge to be met in simulation, an inordinate emphasis is placed on elaborate engineering. The true challenge is to meet "task fidelity" requirements. Task fidelity may be defined as the extent to which the training device imposes the same sensory, motor, and data processing demands upon the trainee as does the actual case. The consensus of much human factors evidence is that when there is an equivalence of task requirements there is effective training. Isley (1968) reports a critical case where physical similarity between the training and actual situation was high, but where task and behavioral demands were not similar. Negative training resulted.

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[1] This chapter on Visual Simulation was prepared by Dr. Hugh M. Bowen of Dunlap and Associates, Inc., and Dr. Knox E. Miller of the U.S. Naval Training Device Center. Dr. Miller prepared subsection 3.1.3 which presents a technique for developing visual simulation specifications. Dr. Bowen prepared the other subsections of this chapter.

With this in mind, this chapter sets out to relate data concerning visual perception to the various operational or tactical situations most commonly found. In this way, it is intended that the designer of the training device can match the requirements for training against the visual characteristics appropriate for the device.

Data concerning vision and visual processes, related as specifically as possible to simulator conditions, are provided first. It is intended that the designer should be able to turn to this subsection, starting with a visual topic in mind (e.g., depth perception), and find useful data and guidance concerning that visual function and its design implications.

Secondly, operational situations are analyzed in visual simulation terms. Typical air-to-air, air-to-ground, on-ground, and in-water situations are considered. The various techniques of visual simulation are reviewed from the point of view of their advantages and limitations as visual media. In addition, a method for evaluating simulation techniques for a particular training application is developed.

Finally, major research issues in the field of visual simulation are discussed.

3.1.2 Basic Visual and Visual Scene Factors.

3.1.2.1 Introduction. The visual environment is defined by the following major visual characteristics:

- Size of field
- Size of objects
- Luminance of objects and background
- Shape of objects
- Color of objects and background
- Distance of objects in the field
- Motion of objects
- Variations in brightness

These characteristics and associated topics will be discussed with specific reference to simulation considerations.

3.1.2.2 Size of Field. From the observer's point of view, the visual scene is limited by the angles of sweep generated by the head and eyes. Table 11 provides the pertinent data.

To what extent is it necessary or desirable to provide the full extension of the visual scene? Data indicate the importance of peripheral vision in maintenance of balance, equilibrium and orientation in piloting (Berens and Shephard, 1952; Hopkin, 1959). Adequate scene perception

TABLE 11. THE LIMITS OF THE VISUAL FIELD UNDER VARIOUS KINDS OF RESTRAINT

		Horizontal Limits		Vertical Limits	
Movement Permitted	Type of Field and Factors Limiting Field	Temporal Ambinocular Field (each side)	Nasal Binocular Field (each side)	Field Angle Up	Field Angle Down
Moderate movements of head and eyes assumed as:	Range of fixation	60°		45°	
Eyes: 15° right or left	Eye deviation (assumed)	15°	15°	15°	15°
15° up or down	Peripheral field from point of fixation	95°	(45°)	46°	67°
Head: 45° right or left	Net peripheral field from central fixation	110°	60°***	61°	82°
	Head rotation (assumed)	45°	45°	30°*	30°*
30° up or down	Total peripheral field (from central body line)	155°	105°	91°	112°**
Head fixed Eyes fixed (central position with respect to head)	Field of peripheral vision (central fixation)	95°	60°	46°	67°
Head fixed Eyes maximum deviation	Limits of eye deviation (= range of fixation)	74°	55°	48°	66°
	Peripheral field (from point of fixation)	91°	Approx. (5°)	18°	16°
	Total peripheral field (from central head line)	165°	60°***	66°	82°
Head maximum movement	Limits of head motion (= range of fixation)	72°	72°	80°*	90°*
Eyes fixed (central with respect to head)	Peripheral field (from point of fixation)	95°	60°	46°	67°
	Total peripheral field (from central body line)	167°	132°	126°	157°**

TABLE 11. THE LIMITS OF THE VISUAL FIELD UNDER VARIOUS KINDS OF RESTRAINT (Continued)

<table>
<tr><th rowspan="2">Movement Permitted</th><th rowspan="2">Type of Field and Factors Limiting Field</th><th colspan="2">Horizontal Limits</th><th colspan="2">Vertical Limits</th></tr>
<tr><th>Temporal Ambinocular Field (each side)</th><th>Nasal Binocular Field (each side)</th><th>Field Angle Up</th><th>Field Angle Down</th></tr>
<tr><td></td><td></td><td colspan="2">60°</td><td colspan="2">45°</td></tr>
<tr><td>Maximum movement of head and eyes</td><td>Limits of head motion</td><td>72°</td><td>72°</td><td>80°*</td><td>90°*</td></tr>
<tr><td></td><td>Maximum eye deviation</td><td>74°</td><td>55°</td><td>48°</td><td>66°</td></tr>
<tr><td></td><td>Range of fixation (from central body line)</td><td>146°</td><td>127°</td><td>128°</td><td>156°**</td></tr>
<tr><td></td><td>Peripheral field (from point of fixation)</td><td>91°</td><td>Approx. (5°)</td><td>18°</td><td>16°</td></tr>
<tr><td></td><td>Total peripheral field (from central body line)</td><td>237°</td><td>132°</td><td>146°</td><td>172°**</td></tr>
</table>

(from Hall and Greenbaum, 1950)

*Estimated by the authors on the basis of a single subject.

**Ignoring obstruction of body (and knees, if seated). This obstruction would probably impose a maximum field of 90° (or less, seated) directly downward, however, this would not apply downward to either side.

***This is the maximum possible peripheral field; rotating the eye in the nasal direction will not extend it, because it is limited by the nose and other facial structures rather than by the optical limits of the eye. The figures in parentheses on the line above are calculated values, chosen to give the maximum limit thus indicated.

NOTE: The ambinocular field is defined here as the total area that can be seen by either eye; it is not limited to the binocular field, which can be seen by both eyes at once. That is, at the sides, it includes monocular regions visible to the right eye but not to the left, and vice versa. The term binocular is here restricted to the central region that can be seen by both eyes simultaneously (stereoscopic vision). It is bounded by the nasal field-limits of the eyes.

is necessary to overcome possible false impressions from body tilt (Witkin and Asch, 1948(a), 1948(b)). The adequate perception of motion is dependent upon the perception of a broad scene (Gibson, 1955) and, particularly, in such tasks as landing an aircraft (Calvert, 1954, 1955). Salvatore's (1968) studies suggest that motion may be judged more accurately in the periphery than foveally. Luria's (1968) data demonstrate that peripheral vision contributes to stereo-acuity. There is, therefore, convincing evidence pointing to the utilization in visual perception of the visual peripheral inputs.

Typically, the workplace enclosures, such as cockpit structure, tend to limit the field of view to the outside. It is generally considered desirable to "fill" the window scenes with scenic material whenever possible. Conant, et al, (1962) caution that a cutoff in the periphery gives not only a false appearance, but a false cue. It is true that an aircraft can be flown and landed with as little as 10° forward vision provided by a periscope (Roscoe and Williams, 1949; Roscoe, 1951). It has been argued that this result justifies a limitation of scene in a simulator. This would seem to argue that because we may be able to manage to get around with blinkers on, there is therefore no difference between normal vision and narrowed vision.

However, the fact that peripheral vision contributes significantly to visual perception, and that peripheral scenes are necessary to provide credibility in the scene, should not be allowed to detract from the obvious fact that the major portion of the visual input is gained in central (foveal) vision. Landing an aircraft, particularly on a carrier in the open sea, is a case where task information is concentrated in central and parafoveal vision (Wulfeck, et al, 1958; Calvert, 1955). For such cases where task fidelity may be preserved with a small visual field, a simulation of only the visual target area which appears in the central 6° visual cone may be acceptable on the basis that training effectiveness can be achieved by this means.

A further consideration of "size of field" is the size of what is termed the "Visual World Envelope." The question is--how big a piece of the visual world is it necessary to present to the trainee? The answer depends, in the case of pilotage, on the mission, speed, altitude, time period of flight, horizontal flight path, time of day/night, etc. Typical data reported by Aronson (1963) are:

- Helicopter navigation: airspeed, 0-140 knots; altitude, 200 to 600 feet above terrain; time of flight, up to one hour; lateral fly area, 1-1/2 miles either side; maximum visible distance, up to 5 miles.

- Fixed wing aircraft: low visibility, landings and takeoffs; airspeed, 0-250 knots; altitude, 0-1000 feet above terrain; total distance in direction of flight, 5-1/2 miles; lateral fly area, 1/2 mile either side.
- Low Altitude High Speed Navigation: airspeed, 600 knots and less; altitude, 50 to 200 feet; total distance in direction of flight, 120 miles; maximum visible range, up to 5 miles; lateral fly area, 1 mile either side.

These typical specifications derive from an analysis of the system's operation in the particular circumstance which is to be trained. It is necessary to specify these particulars in every case to arrive at the desirable "visual world envelope" in any particular case.

3.1.2.3 Size of Objects. The requisite size of objects in visual simulator scenes is a troublesome problem because the discrimination capacity of the eye (visual acuity) is, under the best circumstances, extraordinarily fine. Acuity resolutions down to a few seconds of arc are reported (Graham, 1965). However, acuity under normal viewing conditions is seldom better than a minute of arc and is often appreciably less. The data of Blackwell, et al (1959), are often reported in this context. Bliss (1966), writes of it: "This is the classic report on this subject. No one fails to cite it, and no one knows what to do with the data, since it is the best illustration extant of a hopeless discrepancy between results of carefully controlled simulation tests and carefully controlled flight tests against the same targets."

The discrepancies may be illustrated by the overall averages for all runs in the Blackwell, et al (1959) studies:

Item	Average Slant Range at Recognition	Average Probability of Recognition
Simulation	15,895 feet	0.89
Flight test	11,008 feet	0.60

It has been rather widely assumed that targets need to subtend 12-20 minutes of arc to be recognized. For instance, Steedman and Baker (1960) found that search time for objects became constant when their size was over 12 minutes of arc. A recent and thorough field study (Gilmour, 1964; Gilmour and Iulano, 1964) wherein observers searched for a radar van in an open area of desert country at a height of 200 feet above terrain, at noon, at a speed of mach 0.8, indicated that effective recognition occurred when the subtense angle was approximately 1°. At this level, one is dealing with human perceptual and interpretational capability rather than simple visual acuity. However, as far as the designer of the visual scene is concerned, when an object must be made visible, it is immaterial precisely what visual/perceptual mechanisms are involved.

Certain general guidance can be offered to set limits.

- Visual acuity increases only slightly when brightness is above 10 footlamberts. Below this level, visual acuity lessens at an accelerating rate as brightness lessens (Moon and Spencer, 1944).

- Dynamic visual acuity (DVA), that is, acuity for moving targets, is less than that for stationary targets. DVA lessens as a function of speed of motion. A typical datum point is: when visual acuity is 2 minutes of arc for a stationary target, the target size has to be increased to 10 minutes of arc when it is moving at 140° per second across the observer's line of sight (Ludvigh and Miller, 1958).

- Textured ground scenes (or symbolized scenes, such as random light and dark squares) and patterned cloud layers possessing various levels of fineness of detail provide adequate visual orientation cues (General Electric Company, 1961).

- As brightness contrast improves, visual acuity also improves, almost proportionately (Cobb and Moss, 1954). Luxenberg and Bonnes (1965) offer as "acceptable contrast ratios" on displays:

	Contrast Ratio
White symbols on black ground	5:1
Line drawings or text on a white background	25:1
Pictorial scenes	100:1

  (It is questionable whether a contrast of 100:1 is feasible on many types of displays (Poole, 1966).)

- Target recognition on TV or other displays (e.g., electroluminescent displays) is affected by the number of shades of gray and the number of lines defining the object. Visual performance becomes approximately constant when the number of discernible shades of gray is 8 (Johnston, 1968) and when an object (symbol) is defined by at least 8 lines (Shurtleff, et al, 1965).

3.1.2.4 Luminance of Objects and Background. The eye adapts to the brightness of the scene. The important visual functions (acuity, color perception, depth perception, etc.) reach an approximate constancy when the liminance is 1 to 10 footlamberts (Berry, et al, 1950; Lythgoe, 1952). To simulate daylight conditions, exact physical simulation is not required to give the impression of realism (Puig, 1970). Both brightness contrast and color contrast, serve to perceptually articulate the scene so that objects, textures, patterns, etc., may be seen. Thus, perceptual fidelity may be achieved at low luminance levels if the proper contrast ratios are provided. Buddenhagen and Wolpin (1961) point out that when such effects as dark or brightness adaptation, flash blindness, and glare discomfort are being simulated, brightness scaling problems occur. Interpolation along the visual functions as described in standard texts (e.g., Graham, 1951) is advised. Table 12 provides a listing of representative brightnesses of natural objects covering the entire range of brightnesses occurring naturally. When display of ground scenes is desired and realism is being sought it should be remembered that the apparent brightness (luminance) of objects depends upon the intensity and direction of the illumination, the reflectance of the objects, and the viewer's position with respect to the object.

The visual and optical characteristics of objects and substances have been measured or estimated as follows (Gordon, 1964):

Typical midday outdoor brightnesses are:

Bright Sunlit Cloud	9000 footlamberts
Sandy Beach, Dry	4500 footlamberts
Barren Soil, Light	1800 footlamberts
Green Grass in Sun	700 footlamberts
Dark Soil, Dry	675 footlamberts

The range of luminances in ordinary outdoor scenes averages about 160:1, although extremes of 760:1 have been observed (Jones and Condit, 1941). In specific cases, such as specularly reflectant objects, much higher extremes occur.

Data concerning color of terrain has been reported using the Munsell notation, and is shown in Table 13.

To these aspects of the world which are natural, one must add cultural features. In general, it is recommended that the density of cultural features provided be the same as occurs in the type of landscape being simulated. A desert or the arctic has few cultural features, although the few that are present will tend to be conspicuous. An urban area is dominated by cultural features. The grain of 1 minute arc is considered generally acceptable, although a finer grain may often be desirable.

TABLE 12. REPRESENTATIVE BRIGHTNESS OF NATURAL OBJECTS

Luminance in ml	Objects	Notes
1×10^9	Sun	Sun viewed from outside earth's atmosphere: 7×10^8 ml.
	Sun	Sun viewed from earth: 4.4×10^8 ml.
1×10^8		
	A-bomb	Fireball 4 miles from 800 KT weapon: 8×10^7 ml.
1×10^7		
10^6		
10^5		Upper limit of visual tolerance: 1.6×10^4 ml
	Venus	Albedo approx. 0.6; viewed from outside atmosphere: 1.6×10^4 ml.
10^4	Earth	With cloud cover; from space; albedo 0.8; 9.4×10^3 ml.
	Earth	No clouds; from space; albedo 0.4; 4.3×10^3 ml.
10^3	Sky	Average sky on clear day: 2×10^3 ml.
	Moon	Full moon viewed from earth: 8×10^2 ml.
10^2	Sky	Average sky on cloudy day: 5×10^2 ml.
	Earth	"Average" earth on cloudy day: approx. 1×10^2 ml.
10^1	White paper	In good reading light: 2×10^1 ml.
	Mini screen	Approx. 16 ml. TV screen: approx. 10 ml.
1	White paper	1 foot from ordinary candle: 1 ml.
	Snow	In light of full moon: 8×10^{-1} ml.

TABLE 12. REPRESENTATIVE BRIGHTNESS OF NATURAL OBJECTS (Continued)

Luminance in ml	Objects	Notes
10^{-1}	Limit readable	Brightness level for charts, etc.: approx. 8×10^{-2} ml.
	Lower limit	For useful color vision: 2×10^{-2} ml.
10^{-2}	Earth	From space in moonlight: 7.5×10^{-3} ml.
10^{-3}	Night vision	Upper limit: 1×10^{-3} ml.
10^{-4}	Snow	In starlight: 9×10^{-5} ml.
	Green grass	In starlight and earth seen from space in starlight, airglow, and zodiacal light: 3×10^{-5} ml.
10^{-5}	Lower limit	For night vision; moonless night sky: 1×10^{-5} ml.
10^{-6}	Space	1×10^{-6} ml.

TABLE 13. TERRAIN AND SOME VISUAL CHARACTERISTICS OF A TYPICAL DESERT[1]

Terrain Type	Visual Characteristics
Serrated Mountains	Reddish brown 2.5YR 4/2, 4/3, 5/2, 5/3[2]
Rounded Mountains	Dark gray to dark brown 2.5YR 2/2, 3/2, 4/1
Badlands	Dirty gray 10YR 6/1, 5/2
Wash	Light tan to medium gray 10YR 6/1, 6/2, 6/3
Desert Pavement	Dark brown or black 10YR 3/2, 2/2
Gravel Flats	Light tan to light brown 10YR 7/4, 6/4
Sand Plains	Light tan 10YR 7/3, 7/4
Bottom Lands	Gray-brown or buff 10YR 5/3, 6/2, 6/3 when dry 10YR 3/2, 3/3 when wet

[1] Yuma, Arizona desert.

[2] Munsell notation; hue, value and chroma.

3.1.2.5 Shape of Objects. Shapes, forms, patterns, etc., vary in how easily they are perceived as a function of a multiplicity of quantitative and qualitative factors. The conspicuity of a shape depends on the perceptual set of an observer. For example, in an applied setting, Sturm, et al (1966), found that in visual contact navigational flight, the predesignation of targets and checkpoints served to increase navigational performance by 20 percent (target acquisition and recognition). Predesignation was achieved on radar or on navigational displays in the cockpit.

The visibility of an object depends in complex ways on its scenic context. Camouflage purposefully exploits the possibilities of merging "figure" into "ground," and targets may be "naturally" lost when imbedded among irrelevant forms. A useful review and survey of much qualitative description of these effects is provided in Wulfeck and Taylor (1957).

These cautions concerning "real-life" factors in the perception of form are necessary in order to qualify the geometric and other factors of the form itself which determine its conspicuity. A form is seen, not only as a form, but as an object distinguished from its background. Thus, the greater the brightness and/or color contrast, the more conspicuous the object (Wulfeck and Taylor, 1957).

Objects tend to be more conspicuous when:

- the object is large (Moler, 1962; Taylor, 1954; Miller, 1964),
- the object is singulated in the scene (Boynton, 1957; Deese, 1956; Gilmour and Iulano, 1964),
- the object is sharply defined (absence of blur) (Enoch, 1958; Fiorentini, 1961; Fry and Enoch, 1959),
- the object forms a simple figure, such as square, circle, triangle, straight line, etc. (Collier, 1931; Helson and Fehrer, 1932; Kleitman and Blier, 1928; Whitner, 1933; Casperson, 1950; Bowen, et al, 1960),
- the object conforms to some or all of the following prescriptions:
    - simplicity
    - symmetry
    - continuous contour
    - relatively large enclosed area
    - either sharply angular or simple curve forms
    - familiarity--especially in the sense of having a common name or meaning (Bowen, et al, 1960).

The comprehensive study by Gilmour and Iulano (1964) provides representative data on the relative conspicuity of several targets (Table 14). The tests were conducted in a jet aircraft simulator with the observers viewing a 35 mm color motion picture. Realism was gained by having the movie film record a flight over a 160-mile course at three heights (500, 400 and 200 feet) and at two speeds, mach 0.85 and mach 1.2.

TABLE 14. CONSPICUITY OF TARGETS

Target	Average Acquisition Range (feet)	Probability of Acquisition
Row of mothballed freighters in a bay	12,160	1.00
Long, low, causeway type bridge	8,000	0.86
Large warehouse on dock	7,800	0.94
Bridge and causeway across large river	7,660	0.97
Isolated radio tower and shack	7,140	0.94
Docked battleship	5,590	0.81
Plywood processing plant	4,540	0.89
Gasoline storage tanks	3,590	0.89
Small factory	3,510	0.72
Radio communications station: buildings and antenna	3,400	0.72

(from Gilmour and Iulano, 1964)

3.1.2.6 Color of Objects and Background. Color is a fact of visual reality and, hence, realism is enhanced when a visual scene appears in color. Color may be an absolute requirement in achievement of task fidelity in training situations, such as search for color-coded life-rafts, perception of color-coded pyrotechnics, the simulation of nighttime lighting for takeoff and landing (green boundary lights, red obstruction lights, white runway lights, blue taxiway lights, etc.).

Color contrast (with equal brightnesses of object and background) can be equivalent to a brightness contrast of 35 percent (Eastman Kodak, 1958). Hence, the use of color generally increases the amount of information transmitted by a display (Hitt, 1961; Smith, 1963, Smith and Thomas, 1964). Color contrast is mainly dependent on the saturation of the color. The more saturated, "pure," the color, the more contrast it has to its surround. Color contrast is affected by brightness (too low or too high a brightness are both unfavorable to effective color contrast (Purdy, 1931)) and by the size of the colored patch. For underwater simulation it should be noted that ocean water acts as a blue/green filter gradually eliminating red as depth increases. An exception can occur in very murky river waters where all colors may be shifted toward red (Kinney et al, 1967). Conover and Kraft (1958) suggest that color recognition should not be counted on for objects subtending less than 20 minutes of arc.

3.1.2.7 Distance of Objects in the Field. Actual perception of volumetric space is achieved by a combination of binocular and monocular cues. In nearly all simulations, the volumetric space is much constricted and visual space has to be recreated. Binocular cues can be recreated only by separating the images at the two eyes (see Vlahos (1965), for a survey of techniques and methods). While several methods are available, they have been seldom, if ever, used in training devices. The probable reasons are (1) the incompatibility of the stereoptic condition with normal viewing (e.g., colored or polaroid glasses, curved lens screens, etc.) and (2) that very powerful depth impressions can be obtained from monocular cues.

The first difficulty in simulation of visual depth is that the scene is, in fact, at some physical place close to the observer. Virtual image techniques remove the image to optical infinity, but these techniques are still confined to relatively small scene sizes. When physical projection screens are used, a common practice has been to place the screen 10 feet or so from the observer (Aronson, 1965). However, eye convergence and eye accommodation approach optical infinity conditions for objects at 18 to 20 feet (Wulfeck, et al, 1958). However, screens placed 20 feet from the observer increases greatly the requirements for brightness of the display generating sources, equipment size and space. Experience suggests that a distance between 10 and 20 feet is satisfactory and is a sensible compromise with other requirements. The perception of the actual visual location of the scene is minimized with large-angle screens and absence of any visual structure between the observer and the scene (Puig, 1970).

Monocular cues to depth include:

- relative size,
- relative brightness,
- relative definition (increasing blur with distance),
- texture gradient,
- linear perspective,
- interposition,
- shadows and shading effects,
- motion parallax--when observer is moving, near objects appear to move across distant objects,
- expansion and streaming when observer is in motion.

Any one or a combination of these cues can be the dominant cue, depending on circumstances. It is unsatisfactory to have cue conflict or lack of realism. A common source of lack of realism derives from use of models and the absence of aerial perspective (haze and blur). Particular attention needs to be paid to this feature owing to the often dominating role that aerial perspective plays in depth judgments (General Electric Company, 1961).

A special case is the simulation of underwater conditions. Visibility is restricted because of transmission attenuation of light energy through water. Typical data are presented in Table 15.

TABLE 15. TRANSMISSION ATTENUATION OF LIGHT ENERGY THROUGH WATER

Attenuation Coefficient (α)	Distance at Which 20% of Light Energy Remains
0.05 (exceptionally clear water)	35 meters
0.10 (common tap water)	15 meters
0.33 (typical bay and estuarine waters)	6 meters

(after Loucks, 1970)

3.1.2.8 Motion of Objects. An object moving at about 2 minutes of arc per second against a stationary background will just be seen as moving (Graham, 1965), provided the target is seen for a long enough time--generally 1 or 2 seconds--and the scene is bright enough--10 footlamberts or more (Liebowitz, 1955). In general, the brighter the scene and the longer the viewing period, the easier it is to perceive motion. Motion is also readily seen in the periphery but, due to the decrease of acuity in the periphery, somewhat higher rates of motion are required to achieve threshold values. As compared to 2° per second foveally, the threshold for motion at 70° to 80° in the periphery is approximately 8° per second (McColgin, 1960).

Rates of change of speed are also important to judge in many control tasks, such as landing an aircraft. When the object is moving slowly, 1° to 10° per second, an instantaneous rate of change of about 0.15° per second can be perceived; at higher object rates, up to 25° per second, instantaneous changes of 0.2° to 0.25° per second are threshold values (Hick, 1950; Notterman and Page, 1957).

Objects moving fast enough may blur. Graham (1951) reports that under the best of conditions an angular velocity of 30° per second with respect to the viewing axis will cause blur. Under less favorable conditions 15° per second will cause blur. Miller (1964) has examined the blur areas experienced by a pilot in a low-flying aircraft. However, the "blur maps" which are developed, assuming that the pilot is looking straight ahead, are somewhat unrealistic because an object of interest will be fixated and visually tracked.

Apparent motion may be induced by a variety of effects. In general, when the physical situation replicates the conditions of a real motion to a sufficient degree, the observer mistakenly sees motion. A walk in an urban district at night will demonstrate the varieties of effects that can be produced by neon signs. Graham (1955) discusses the conditions necessary to produce apparent motion effects.

Motion of the field, produced by observer motion through the field, produces the kinetic cues of flow, motion parallax, expansion-patterns, etc. (Gibson, 1955). In addition, the motion has effects on visual performance. Search performance in the visual periphery was found by Erickson (1964) and Williams and Borow (1963) to be impaired at field movements greater than 7° to 8° per second. However, various operational studies, for example, Joska (1953), Gilmour (1964) and Gilmour and Iulano (1964), have suggested that speed over the ground has little effect on search performance, within the range of speeds studied (mach 0.4, 0.6, 0.8, 1.0, (1.2 in the Gilmour study). It is thought that observers may compensate for blurring and time-stress effects by modifying their visual search patterns.

A common practical simulation problem is the presentation of the changing visual scene when landing. Calvert (1954, 1955) stresses the importance of the "form" cues and the transformation which the runway geometry goes through as a function of the travel of the aircraft. Gibson (1950) emphasizes the "focus of expansion" and the streaming effects as the aircraft is flown down the glide slope to touchdown. Payne, et al (1954) report that pilots feel that ground texture, perspective cues, and opposed motion of ground objects are the significant visual cues in landing. The consensus would appear to be that pilots may and sometimes do use all of the many cues in the scene. The pilot sees the scene as a whole and forms his ongoing percept from combining the information available to him. While he can perform with diminished cues, Roscoe (1951) has shown that his performance suffers.

3.1.2.9 Variations in Brightness (Temporal Factors). The perception of motion may be considered to be a special case of variation of the scene or scene elements over time. Other effects, often of an unwanted nature but sometimes useful for display encoding purposes, are flicker, glitter, strobing and fading.

Flicker is a major source of brightness interference for simulation designers. Changes in brightness, caused by display repetition rates, scanning techniques, and pattern spacing, may cause flicker. In addition to impairing image fidelity, flicker causes impairment in perception and may occasion nausea, dizziness and fatigue. Critical Fusion Frequency (CFF) is the rate above which an intermittent source is not seen to be intermittent. CFF is determined by a multiplicity of factors, including the following (Ross, 1936; Hecht and Schlaer, 1936; Graham, 1965):

- the individual observer
- the age of the observer
- the location on the retina stimulated
- the area of retina stimulated
- the duty cycle (on/off ratio) of the source
- the color of the source (at low light levels)
- brightness.

Of these determinants of CFF, the single most important factor is brightness.

At 1 footlambert, CFF is approximately 32 c.p.s
At 10 footlamberts, CFF is approximately 43 c.p.s
At 100 footlamberts, CFF is approximately 55 c.p.s.

Various special forms of flicker may occur. A relatively common one is the stroboscopic interaction of the moving eye with an intermittent source (Bowen and Guinness, 1964). Characteristically, a "jumping" effect is observed when the source is small and bright; it is due to successive images striking different points in the retina during eye movements. The basic remedies for flicker effects are to increase the "on" phase of the duty cycle and to speed up the flicker rate as much as may be possible. In general, it should be recognized that high brightnesses, small light sources and intermittency are together the ingredients for unwanted motion to be seen.

The material thus far provides basic information concerning the human visual function pertinent to simulation design. In the next subsection (3.1.3) a means for achieving an effective visual environment for the purpose of training is described. A technique is presented which will provide assistance for decisions on visual simulation equipments needed for specific training applications.

3.1.3 A Technique for Developing the Visual Simulation Specifications.

In the development of performance specifications for visual simulation equipment to be used for training, the initial and most important step is the selection of an engineering approach appropriate to the problem. Although the results of this selection process are expressed in terms of an engineering specification the decision involves far more than engineering considerations alone. The decision process is a dynamically interactive one and should involve an interdisciplinary team of mechanical or electronic engineers, Human Factors Specialists, Physicists, computer programing specialists, and personnel experienced in the operational environment to be simulated. Often, the basic advantage of an interdisciplinary approach is not properly exploited simply because the information which is available is scattered, poorly organized and poorly communicated within the team. The purpose of this subsection is, therefore, to describe and illustrate the use of an analytic technique designed to: 1) collate the scattered bits and pieces of information about any specific visual simulation problem as seen from the standpoints of the various team members, 2) organize this information in a systematic (albeit arbitrary) manner, and 3) display the resulting data in a format which will permit direct comparison of the relative advantages and disadvantages of competing hardware systems.

The technique described here requires a detailed knowledge of the constraints imposed on the hardware selection process by the following factors; a) the characteristics of the operational environment to be simulated, b) the perceptual requirements of the specific mission or mission segment involved; and c) the functional characteristics of the simulation hardware under consideration. It should be made clear that this technique does not abridge in any way the responsibilities or the prerogatives of the individual team members in arriving at their joint decision. It should, rather, be regarded as a convenient method of organizing and displaying the information already available.

The ultimate value of this approach depends in part on the degree of active participation by the individual team members. Although the basic technique can be profitably employed on an individual basis the data will more accurately reflect the combined knowledge of the group if each member makes his unique contribution to the analysis.

In essence, the method consists of a logically based fractionation of visual simulation requirements (derived from a) and b) above) on the one hand, and simulation system characteristics on the other, into units of a size which will permit the known facts about each to be arrayed in a series of simple decision matrices. Thus, for each combination of vehicle/mission segment (e.g., fixed wing, low altitude navigation), and candidate simulation system (e.g., CCTV-Model) a number of matrix "scores" can be derived, each of which represents for a given characteristic, the degree to which the simulation system in question meets the requirements imposed by the specific environment/mission to be simulated. When the individual matrix scores are graphically displayed as a function of the arrayed simulation requirements, a profile is obtained in which the relative strengths and weaknesses of the simulation system under consideration are made readily apparent. Comparison of the profiles derived for each of several candidate simulation systems as a function of the same set of simulation requirements thus provides a logical and objective basis for the selection of hardware.

Since most forms of vehicular control are strongly dependent upon visually derived inputs it is apparent that the need for visual simulation in training equipment spans the entire gamut of military environments. While vehicular control training is the primary source of visual simulation requirements there are additional requirements derived from the need to provide training intactical interpretation of visual signals which are themselves processed representations of the real world, such as radar and sonar.

Although the number and variety of potential visual simulation problems is very large, those associated with vehicular control can be logically classified and organized in terms of a) the operational environment (e.g., air-to-ground, waterborne, etc.), b) the type of vehicle (fixed-wing, surface ship, etc.), and c) the mission or mission segment (e.g., low altitude visual navigation, harbor navigation, etc.) which they represent. The remainder consist of artificial sensor display problems and a few special cases which are distinct from but so closely related to visual simulation that they are often considered under the same rubric. The classification scheme adopted for the purposes of this analysis is presented in Table 16. This particular classification while not definitive, has proved useful because it permits the total mission for a given weapon system to be broken down into meaningful segments, each of which is well enough defined to be dealt with on an analytic basis. For example, a carrier-based attack aircraft on a strike mission might conceivably involve several of the individual mission segments (shown in Table 16) each of which has certain implications for the simulation hardware to be employed.

Simulation of the complete strike mission (including carrier take-off and landing, low altitude visual navigation, target acquisition, weapons delivery, etc.) therefore, requires cascading of the analytically determined hardware constraints associated with each of the mission segments involved. Such progressive restriction of alternative solutions quickly reveals that there is at present no single technique capable of providing a satisfactory solution to the requirement for a total strike mission simulator. But more importantly, this technique can be used to reveal the extent to which various mission segments (part-tasks) can be combined in practical and reasonably cost-effective training equipment.

The number of engineering approaches available to solve the problems defined by the selected mission segments is limited. These approaches are listed in Table 17. While this listing is not inviolate, the intent is to include all of the various technologies which have or can be used to generate, store, transfer and display imagery for the purposes of visual simulation.

As previously stated, the successful application of this technique requires a more or less detailed knowledge of the relative strengths and weaknesses of the simulation hardware available. At the very least, the

TABLE 16. MILITARY VISUAL SIMULATION PROBLEMS

I. Vehicle Control Problems
    A. Airborne Vehicles
        1. Air-to-Air Environment
            a. Fixed Wing
                (1) Combat Maneuvering
                (2) Air-to-Air Refueling
            b. Rotary Wing
                (1) Tactical Formation Flying
                (2) ASW Station Keeping
        2. Air-to-Ground Environment
            a. Fixed Wing
                (1) Visual Navigation
                (2) Visual Reconnaissance
                (3) Target Acquisition
                (4) Weapons Delivery
                    (a) Bombs
                    (b) Visually guided missiles
                    (c) Gunnery
                        1. Fixed
                        2. Flexible
                (5) Takeoff/landing (fixed base)
                    (a) Night
                    (b) Day
                (6) Takeoff/landing (carrier-based)
                    (a) Night
                    (b) Day
            b. Rotary Wing

TABLE 16 MILITARY VISUAL SIMULATION PROBLEMS (Continued)

        - (1) Visual Navigation
        - (2) Visual Reconnaissance
        - (3) Target Acquisition
        - (4) Weapons Delivery
            - (a) Visually guided missiles
            - (b) Gunnery (flexible)
    - c. Remotely Controlled (TV guided) Missiles

- B. Surface Vehicles
    - 1. Land Based Environment
        - a. Off Road Vehicles
            - (1) Tanks/tracked Vehicles
            - (2) Air Cushion Vehicles
        - b. Conventional Vehicles
    - 2. Waterborne Environment
        - a. Surface(d) Ship Control Problems
            - (1) Harbor Navigation
            - (2) Ship/submarine Mooring
            - (3) Ship/submarine Docking
            - (4) Ship-to-Ship Underway Replenishment
        - b. Small Boats and Special Purpose Waterborne Vehicles
            - (1) Assault Boats
            - (2) Hydrofoil
- C. Subsurface Vehicles
    - 1. Subsurface-to-Surface Environment (Periscope Simulation)
        - a. Approach/attack
        - b. Reconnaissance
        - c. Navigation
    - 2. Subsurface Environment (in-water simulation)

TABLE 16. MILITARY VISUAL SIMULATION PROBLEMS (Continued)

II. Artificial Sensor Display Problems

- A. Radar/radar landmass
- B. Sonar
- C. IR
- D. TV-Data Link
- E. ECM
- F. Compound types

III. Special Information Display Problems

- A. Status and Large Area Tactical Information Displays

TABLE 17. BASIC VISUAL SIMULATION SYSTEMS

1. Optically Viewed Models
2. Closed-Circuit TV Viewed Models
3. Point Light Source - Transparency
4. Open-Loop Movie
5. Servoed Projections
6. Semi-Closed Loop (VAMP) Movie
7. Computer-Generated Display
8. Flying Spot Scanner - Factored Transparency
9. Laser/Holographic Displays
10. Hybrid Systems

human factors psychologist must understand the major advantages and disadvantages of each of the competing systems under consideration. To the extent that this information can be refined or extended thru the participation of a systems engineer experienced in visual simulation (interdisciplinary team effort) the precision of the resulting analysis can be improved.

It is not our purpose to present an exhaustive analysis and detailed comparison of the specific characteristics of each of these systems. Rather, it is assumed that the reader either possesses or has available to him the background information required to relate these system characteristics to the perceptual requirements of the training situation. However, it is desirable from the standpoint of orientation to review briefly the principal features of each basic system.

1. Optically viewed models.

   a. Typical application - periscope view simulation.

   b. Primary advantages - high resolution, closed loop operation, realistic cues to depth, true colors available.

   c. Primary disadvantages - low brightness, narrow angle of view, difficult scaling problems.

2. Closed Circuit Television -viewed models.

   a. Typical Applications - air-to-ground target acquisition, carrier landing.

   b. Primary advantages - moderately high resolution at moderate brightness levels, closed-loop operation, realistic depth cues, electronic manipulation of imagery possible (raster shrinking, video insertion, selective blanking, etc.).

   c. Primary disadvantages - narrow angle of view, difficulty in achieving flexible scaling.

3. Point Light Source and Transparency Systems.

   a. Typical application - approach and landing simulators.

   b. Primary advantages - extremely wide angle field of view available, closed-loop operation, full color easy to provide.

c. Primary disadvantages - low resolution and low brightness, poor depth cues, difficult scaling problems.

4. Open-Loop Movie

a. Typical application - low altitude navigation and target acquisition simulators.

b. Principal advantages - high-resolution, high brightness, full color, extremely wide angle of view, good depth cues available, scaling inherent in film.

c. Principal disadvantages - open-loop operation, difficulty in acquiring adequately controlled imagery.

5. Servoed projections

a. Typical application - Redeye Moving Target simulator.

b. Primary advantages - high resolution, high brightness, extremely wide angle field.

c. Primary disadvantages - reversed contrast of targets (target appears as bright image against dark background), open-loop operation.

6. Semi-Closed Loop (VAMP) Movie.

a. Typical application - takeoff and landing simulators.

b. Principal advantages - high resolution, high brightness, full color, good depth cues, scaling inherent in film, semi-closed loop capability permits limited maneuvering within a narrow envelope.

c. Principal disadvantages - deliberately introduced optical distortion, difficulty of acquiring proper imagery.

7. Computer Generated Displays.

a. Typical application - takeoff and landing, air-to-air combat maneuvering, ship docking and station keeping, etc.

b. Principal advantages - closed-loop operation, scaling inherent in programing, independent motion available within visual field, resolution and color elements can be differentially apportioned according to areas of interest, entire simulation problem can be changed or the elements within a problem updated by programing.

c. Principal disadvantages - relatively high system and software costs, imagery consists of line drawings or discontinuous cartoon-like figures.

8. Flying Spot Scanner - Transparency Systems.

a. Typical application - radar landmass simulators.

b. Principal advantages - closed-loop operation, method of reading out information (density along narrow beams sequentially scanned by a small spot) produces very good analogue of a scanning radar beam.

c. Principal disadvantages - resolution poor at low simulated altitudes, high cost of producing properly coded transparencies at scale factors required.

9. Laser/Holographic Displays.

a. Typical applications - high brightness, large screen tactical situation displays, carrier landing simulators.

b. Principal advantages - very high brightness, multiple colors, and variable persistance of photochromically recorded laser images makes them ideal for large screen status displays. Three dimensional quality of holographic imagery is valuable in simulating carrier landing, ship docking, etc.

c. Principal disadvantages - narrow angle available with Holograms, monochrome images, experimental nature of current technology.

10. Hybrid Systems (employing a combination of two or more of the basic approaches outlined above).

a. Typical application - visual mission, for example, simulator for the A-7D WST. This proposed system was to provide visual simulation for takeoff, low altitude navigation, target acquisition, weapon delivery and landing, by incorporating the basic characteristics of a transparency based terrain model, and a semi-closed loop (VAMP-type) projection system.

b. Principal advantages - high brightness, high resolution, full color, semi-closed loop capability.

c. Principal disadvantages - narrow angle of view, cumbersome solution to scaling problems (necessity for repeated alternation of imagery stored in film cassetts), at least seven separate sources of distortion whose effects cumulate in unpredictable ways.

It will be apparent to the experienced reader that the simplified summaries presented above could be questioned in specific instances. For example, it could be argued that TV-based systems are not necessarily limited to narrow fields of view. However, in order to achieve a wide field one must sacrifice both resolution and brightness or accept the problems inherent in achieving and maintaining image registration in multiple adjacent displays. Similarly, it could be pointed out that the narrow angle of view which is characteristic of optically viewed systems is not a serious disadvantage in periscope view simulations. In this case the angle of view is a disadvantage of the general system type, though not in the application cited.

It should be noted that in listing the relative advantages of the various systems, two different types of features are cited. Some features such as resolution, brightness, distortion and displayed angle of view are usually considered basic parameters of any visual simulation system. Other features such as the ability to provide independent motion of targets within the visual scene, the relative difficulty in making changes in the stored imagery and whether or not the image storage medium is capable of providing adequate cues to depth are not ordinarily thought of as system parameters. Although the distinction between them is somewhat arbitrary it is a significant one since the most important aspect of this analytic technique is that it deals explicitly with those factors which are important in the selection of simulation hardware but which are not recognized as quantitative system parameters. These are the somewhat nebulous, difficult to quantify but highly important considerations which are usually a product of each individual team member's experience. As such they often play a decisive but implicit role in the decision-making process. The basic problem with such experientially-dependent decisions lies in the individual variations with regard to the implicit definitions of these factors and in the relative weights assigned to each. By identifying and explicitly defining as many of the system characteristics which bear on the hardware selection process as possible this analysis will enable the individual or team to arrive at their decisions on a more logical basis. The system characteristics to be considered for the purpose of this analysis are listed and, where necessary, discussed below.

3.1.3.1 Visual System Characteristics.

3.1.3.1.1 Scaling. This characteristic is concerned with the degree to which the medium used to store visual information is able to provide a simulated maneuvering area sufficient to meet the requirements without the necessity of changing scale factors. For example, for the purpose of low altitude visual navigation training, the inflexible scaling of the CCTV-model system is a severe disadvantage because of the conflicting requirements for high resolution and large area coverage. On the other hand, for a simulation problem such as ship-to-ship--underway replenishment involving the approach and station keeping of two large objects on an essentially flat, featureless and infinite plane (the open sea) this characteristic does not constitute a disadvantage for the CCTV system.

3.1.3.1.2 Resolution. This is one of the main physical parameters of any system. For the purpose of this analysis, however, the specific values are less important than the gross categorization of systems in terms of whether their resolution is representative of optical quality, photographic quality or TV quality.

3.1.3.1.3 Detail Requirements. This characteristic refers to the amount and type of detail which must be available in the visual scene to meet the mission requirements. It therefore defines the problems to be solved in the selection and encoding of visual information for storage. As one might expect, the importance of this characteristic varies widely depending on the image storage medium involved. For example, it is relatively unimportant in most photographically based systems, becomes a significant factor in the design of CCTV-model systems and is a critical aspect of computer-generated systems.

3.1.3.1.4 Color Capability. This characteristic refers to the fidelity of color reproduction of the system. For the purpose of this analysis only gross categorization is required. Systems can be classified simply on the basis of whether they are capable of producing black and white only, partial color as in systems based on 2-color mixtures, or full color as in systems based on 3-color mixtures or optically viewed models.

3.1.3.1.5 Absolute Brightness. This is a basic parameter of all simulation systems. For obvious reasons low absolute brightness is frequently a serious disadvantage of systems designed to provide extremely wide fields of view.

3.1.3.1.6 Contrast Range. This is a self-explanatory system characteristic. In general, however, if a system delivers adequate brightness the contrast range will also be adequate.

3.1.3.1.7 Distortion Tolerance. In the context of this analysis this characteristic refers to the perceptual acceptability of simulation imagery which has been purposely distorted by the system, as in the VAMP-type semi-closed loop movies.

3.1.3.1.8 Flicker Tolerance. This is a basic factor in both TV and motion picture systems. Although it does not usually present a problem, it can be a serious disadvantage in some applications of extremely wide angle motion picture systems.

3.1.3.1.9 Accommodation to Infinity. In the context of this analysis this characteristic refers to the relative ease or difficulty of displaying the obtained imagery in such a way that it appears at infinity. For example, some systems lend themselves to the use of relatively compact virtual image displays, while others require that the image plane be physically remote from the viewer, therefore resulting in a large and expensive installation to achieve the same effect.

3.1.3.1.10 Relative Motion. This factor is concerned with the angular velocities expected on the basis of mission requirements and with their anticipated effects on various system parameters such as image smear, stroboscopic effects, and the detail requirements of the storage medium.

3.1.3.1.11 Independent Closed-Loop Motion. This characteristic refers to the relative ease or difficulty in providing independent closed-loop motion of targets within the simulated visual environment. For some missions such as air-to-air combat maneuvering this capability is essential. A mission segment such as weapon delivery (including all types of missiles, fixed and flexible gunnery), which requires the provision of visual ground-effects, constitutes a special case in that the position of impact is determined by ballistic computation (i.e., the control loop is closed mechanically or electronically rather than manually). Simulation systems differ widely in their ability to provide this feature. For example, while it is possible to utilize a CCTV-model system for air combat simulation, the solution is necessarily large and complex. Computer-generated displays, however, are well suited to such problems and, in addition, can provide any type of weapons effects desired, including even tracer paths.

3.1.3.1.12 Coupled Motion. This factor is concerned with the feasibility of coupling a motion platform with the visual system under consideration to provide the integrated sensory cues required for vehicle control training. Mission considerations dictate both the requirement for, and the degree of coupling. For example, for stable and slow-moving vehicles such as ships involved in harbor navigation and in docking, visual representation of the motion cues is sufficient in itself. Simulation of an assault boat landing, however, requires precise coupling of the two systems because the vehicle control task is critically dependent upon the relationship between the visual and motion cues.

3.1.3.1.13 Closed- vs. Open-Loop Operations. This basic parameter is determined by whether or not control actions are fed back into the system. In open-loop systems there is no control feedback and the resultant imagery is fixed or programed as in most vehicle control simulations or mechanically as in the simulation of weapons effects which was mentioned earlier. The critical importance of this parameter in many training situations is due to the fact that closed-loop operation demands active participation of the trainee in accomplishing the control task and provides feedback to him concerning degree of success. Special techniques are available to achieve these ends in certain types of open-loop simulation but in general they are more limited in their application and therefore less satisfactory.

3.1.3.1.14 Angle of View. This is a critical parameter in the design of simulators for many training purposes. Other things being equal, it is desirable to provide the widest angle of view achievable. Some mission requirements, however, are more stringent than others in this respect. For example, for air-to-ground weapons delivery, a wide angle of view is desirable but not essential since bomb, missile and fixed gunnery targets will generally be close to the flight path. On the other hand, for simulation of the low altitude navigation problem visual information from the extreme periphery is essential and therefore an extremely wide angle display is required.

3.1.3.1.15 Depth of Field. This is a basic parameter which does not usually constitute a problem for most system/mission combinations, since in most cases the actual distance from optical probe to area of interest is sufficiently great that a normal optical system stopped down to a small aperture will yield adequate depth. A very small lens aperture, of course, creates other problems such as the necessity to either increase the illumination level or the sensitivity of the recording device. There are, however, mission specific situations in which depth of field does present a serious system limitation independent of both brightness and sensitivity, e.g., when an optical probe is required to come very close to a surface such as in a CCTV-model simulation of carrier takeoff and/or landing.

3.1.3.1.16 Ease of Change. This factor refers to the relative ease of making changes in the visual information which is already coded and stored in the system. It is, of course, related to, but not identical with the scaling factor discussed earlier. While flexible scaling refers to the complete replacement of one stored visual environment by another having a different scale factor, ease of change refers to the relative simplicity of updating an existing image store by making small localized changes. This characteristic can be illustrated by comparing the photographic (factored transparency) and the computer-generated approaches to radar land mass simulation. Factored transparency systems which represent geographic and cultural features as a function of elevation in one transparency and as a function of radar reflectivity in another, cannot be updated when, for example, radar targets such as bridges, highways, dams, reservoirs, etc., are created or destroyed. It is, of course, apparent that computer-generated imagery can be updated with ease by appropriate programing changes.

3.1.3.1.17 Monocular Movement Parallax. This is one of several factors concerned with the cues which govern the perception of apparent depth in the imagery delivered by a system. Monocular movement parallax refers to whether or not objects in the background of a scene appear to move in relation to the foreground, as a function of relative motion between the observer and the target area. Since both the direction and velocity of this apparent motion constitute cues to the depth of an object in the real world, this factor is a powerful determiner of the corresponding illusion in the simulated environment. Generally, monocular movement parallax is based upon three-dimensional inputs since it depends upon constantly changing aspect angles between the recording device and objects in the visual field. Although a regularly changing target aspect angle is a necessary condition for deriving the movement parallax depth cue, it is not in itself sufficient; the target aspect angles must be changing at or above some threshold value. The practical significance of these considerations is that, taken together, they define a range limitation for some missions (e.g., air-to-ground target acquisition, remotely controlled (TV) guided missiles) beyond which depth cues based on this principle will not be effective.

3.1.3.1.18 Interposition. This, like monocular movement parallax, is another of the basic cues to depth. However, unlike the former, the illusion of depth is not dependent upon motion but upon the individual's learned response to certain characteristics of identifiable patterns. Through experience, an individual learns to interpret certain shapes as representative of certain classes of objects. When the expected image of a man interrupts or cuts off a portion of the image to be expected of a tree, the man is interpreted as being in front of (closer to the observer than) the tree. Provided that the geometric relationships between the relative size of known objects is preserved, within very broad limits, interposition is a simple but very powerful cue to depth. Most simulation systems which are based upon three-dimensional inputs (optical or TV-viewed scale model, movies based on either the real world or models of it) provide this cue automatically. Artificially calculated visual environments (e.g., computer-generated imagery, animated motion pictures) can also provide these cues but at some cost in programing effort. In some cases, however (e.g., point light source - transparency systems), the inability to provide this cue is a substantial disadvantage of the system.

3.1.3.1.19 Physical Size. This is an obviously important aspect of any system in that it is closely related to overall cost. In the context of this analysis only gross categorization is necessary. These categories are defined as follows: (1) small--desk-top to small classroom size, (2) medium--a space requiring special preparation such as an unusually high ceiling, a false floor, special cooling arrangements, etc., and (3) large--requiring a special building, exceptionally large room, or an unusually extensive modification of an existing building.

3.1.3.1.20 Power Consumption. This is another cost-related parameter which both reflects and is reflected in the size, weight, illumination and cooling requirements of the system. For the purpose of this analysis the following categories are defined:

(1) small--up to 10 KW
(2) medium--10 to 50 KW
(3) large--over 50 KW

3.1.3.1.21 Original Hardware Cost. For the purpose of this analysis the following categories are defined:

Low--up to 250K
Medium--250K to 1.5M
High--above 1.5M

3.1.3.1.22 Original Software Costs. For the purpose of this analysis, original software costs are classified as follows:

Low
Medium
High

3.1.3.1.23 Maintenance Costs. This factor includes both hardware (parts replacement and equipment repair) and software (programing) support required for adequate availability. For the purpose of this analysis maintenance costs are classified as follows:

Low
Medium
High

On the basis of the foregoing discussion, it is apparent that the importance to be attached to any individual system characteristic varies widely depending on both the mission and the simulation system involved. Specifically, it should be noted that:

a. While all of the 23 characteristics cited are relevant to some combination of mission segment and simulation technology, few, if any, have relevance for the entire range of such possible combinations.

b. A given system parameter, such as resolution (which is a quantitatively measurable aspect of any display system), is a significant characteristic only if it is substantially greater than, or less than, that required on the basis of mission considerations. For example, if the available system resolution exceeds the resolution required to simulate a given operational environment, the proposed system represents a significantly "overengineered" (and therefore overpriced) solution in respect to this particular parameter. Similarly, wherever the system capability is substantially less than the requirement, the parameter in question constitutes a significant disadvantage of the system for that specific application.

c. While only those systems characteristics for which requirements and capabilities are for some reason unequal are to be considered significant, it is apparent that not all significant characteristics are important from the practical standpoint. This is because the nature of our primary interest necessarily emphasizes the disadvantages or shortcomings of competing technologies rather than their advantages. For example, in our context, a parameter which is identified as a system advantage for a given application usually requires no further consideration. Conversely, a characteristic identified as a system disadvantage must be further considered in terms of its criticality, i.e., a system disadvantage may be either a critical or a non-critical factor in the ultimate hardware selection process. The designation of individual system characteristics as important or critical in achieving a specified simulation goal is a judgment which requires considerable knowledge and experience on the part of the individual or team involved. These judgments constitute an important step in the overall decision process in that they identify those difficulties which must be overcome by each of the candidate technologies in order to achieve the desired objective. In terms of this analysis, a critical system deficiency for any specified application is defined as one which can be circumvented only at considerable cost to the system, in terms of money, complexity, development time, maintainability and engineering risk.

3.1.3.2 Application of the Technique. The application of this technique to an actual visual simulation problem is illustrated in the remainder of this subsection with an analysis of three candidate simulation technologies as a function of the same set of simulation requirements. The low altitude visual navigation problem (see Table 18) is selected because of the stringent requirements it imposes on the hardware solution with respect to several important system characteristics, viz., angle of view, scaling, resolution, depth cues, and the desirability of closed-loop operation. This mission segment will be analyzed in terms of the characteristics of 1) CCTV, 2) open-loop movie, and 3) computer-generated simulation systems. The analysis will result in three separate system characteristic profiles on the basis of which the relative strengths and weaknesses of each of the candidate systems can be compared.

In addition, the effect of individual vs. team participation in the analysis will be demonstrated by presenting two separate profiles derived from the same basic information. That is, for a single mission/system combination, two independently derived profiles will be presented--one showing the results of an analysis from the standpoint of a human factors specialist, the other based on the combined or "team" judgments of a human factors specialist and a systems engineer. Examination of the similarities and differences in the profiles will illustrate the refinement and increased precision of analysis which can be achieved by integrating the complementary skills and knowledges of the individual participants into a team effort.

The format adopted for the multiple decision matrices is illustrated in Figure 22. Except for a few cases, which will be noted below, all matrices are identical, consisting of nine cells in a 3x3 block arrangement. There is an individual matrix for each of the 23 system characteristics (e.g., scaling, resolution) previously discussed. Each of these general system characteristics is evaluated in terms of the mission-derived simulation requirements on the vertical axis, and the specific system characteristics available on the horizontal axis. Each cell of the matrix is prenumbered with a "value" ranging from -2 to +2. The specific digits in themselves have no quantitative significance--they could be letters or arbitrary symbols. (It is, of course, a possibility--with further development--that these values could be assigned quantitative significance, if appropriate empirical weightings were established for each system characteristic.) The primary feature of each matrix is that the digits are arranged so that a "0" score is obtained whenever, in the judgment of the individual or the team making the analysis, the simulation requirement as determined by the nature of the mission is met by the specific characteristic of the system under consideration. Matrix cells containing negative numbers will be obtained when in the judgment of the analyst(s) the specific system characteristic is not adequate to meet the requirement. Similarly, a positively numbered cell indicates an unneeded or excess capability of the system in question for the purpose of achieving the defined objective. It should be noted that, since the format of the matrices is essentially uniform throughout, the specific judgments required for each of the requirement/capability combinations vary somewhat. For example, some matrices are simply labeled high, medium and low on each of the axes (viz., detail requirement, absolute brightness, contrast range, ease of change). In these cases, which tend to be associated with basic system parameters, the judgments to be made are, (a) what level of the specific characteristic is required on the basis of the known facts about the mission, and (b) what is the gross ability of the system in question with regard to the specified characteristic. In some cases (e.g., resolution, color, relative motion, angle of view,

TYPE OF VEHICLE & GENERAL MISSION: ___________
SPECIFIC MISSION SEGMENT: ___________
SYSTEM TYPE ___________

VISUAL SIMULATION REQUIREMENTS		SYSTEM CHARACTERISTICS		
		Primary Advantage	Secondary Advantage	Primary Disadvantage
Flexible Scaling	Required	0	-1	-2
	Desired	1	0	-1
	Not Necessary	2	1	0

		High	Medium	Low
Detail Requirement	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		High	Medium	Low
Brightness	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Optical	Photo	TV
Resolution	Optical	0	-1	-2
	Photographic	1	0	-1
	TV	2	1	0

		Full	Partial	Absent
Color	Full	0	-1	-2
	Partial	1	0	-1
	Absent	2	1	0

		High	Medium	Low
Contrast Range	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Inherent Distortion		
		Low	Medium	High
Distortion (tolerance)	Low	0	-1	-2
	Medium	1	0	-1
	High	2	1	0

Figure 22. Format for the Multiple Decision Matrices

VISUAL SIMULATION REQUIREMENTS

SYSTEM REQUIREMENTS

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Accommodation to Infinity	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Independent Motion of Targets in Field	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Unprgmd	Semi-Prgd	Prgrmd
Control of Visual Environment	Unprogramed	0	-1	-2
	Semi-Prgmd	1	0	-1
	Programed (closed loop)	2	1	0

		Degree of Flicker		
		None	Medium	High
Flicker (tolerance)	None	0	-1	-2
	Medium	1	0	-1
	High	2	1	0

		Susceptibility to Smear		
		Low	Medium	High
Relative Motion of Targets	High < Vlcty	0	-1	-2
	Medium < Vlcty	1	0	-1
	Low < Vlcty	2	1	0

		Difficulty/Expense of Providing Required Coupling		
		Low	Medium	High
Coupling of Visual Field with Real Motion	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Wide	Medium	Narrow
Angle of View	Wide (140° up)	0	-1	-2
	Medium (90°-140°)	1	0	-1
	Narrow (less than 90°)	2	1	0

Figure 22. Format for the Multiple Decision Matrices (cont.)

VISUAL SIMULATION REQUIREMENTS		SYSTEM REQUIREMENTS		
		Extensive	Moderate	Small
Depth of Field	Extensive	0	-1	-2
	Moderate	1	0	-1
	Small	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Monocular Movement Parallax	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		High	Medium	Low
Ease of Changing Visual Environment	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Interposition (Terrain Masking)	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

	Small	Medium	Large
Size of Installation	0	-1	-2

	Low	Medium	High
Original Hardware Cost	0	-1	-2

	Low	Medium	High
Maintenance Cost	0	-1	-2

	Low	Medium	High
Power Consumption	0	-1	-2

	Low	Medium	High
Original Software Cost	0	-1	-2

Figure 22. Format for the Multiple Decision Matrices (cont)

etc.) the same basic judgments are required, but for convenience, the axes are labeled in terms of the characteristic itself. Thus, angle of view is labeled in terms of wide, medium and narrow; color in terms of full, partial or absent.

Another type of judgment is required for such qualities or system characteristics as independent motion, flexible scaling, accommodation to infinity, monocular movement parallax and interposition. In these cases, the pertinent judgments are; (a) whether the characteristic in question is required, desirable or unnecessary in order to achieve the simulation objective as defined by the mission, and (b) whether the characteristic constitutes a primary advantage, a secondary advantage, or a primary disadvantage of the system under consideration.

Finally, with respect to several cost-related factors such as power consumption, maintenance costs, etc., the usual nine cell matrix is reduced to three. This is because by definition, only low cost, low maintenance, low power consumption, etc., are required (i.e., desired).

The format of the system characteristic profiles derived from the multiple matrix scores is illustrated in Figure 23. The 23-system characteristics selected for analysis are arrayed along the horizontal axis and individual matrix scores are plotted vertically. When the individual points are connected, a "profile" is formed which graphically portrays the ability of the simulation system under consideration to meet the simulation requirements of the selected mission. Though a given profile is concerned with the "fit" of only one system/mission combination, successive analyses can be made for each of several candidate systems in order to provide a basis for comparing alternative engineering solutions.

As mentioned previously the analytic procedure outlined here is not a substitute for the team's decision-making process in selecting an engineering approach to solve a given simulation problem. It does, however, insure that competitive (but often vastly different) technologies are evaluated logically and systematically on the same bases.

The results of the matrix analyses of the three candidate simulation systems with respect to the simulation requirements of the low altitude visual navigation mission are summarized next. Each of the three profiles shown (CCTV model, open-loop movie, computer-generated imagery) is based on the judgments of an individual evaluator (human factors specialist). For the low altitude visual navigation problem three system characteristics were designated as critical factors. These are, in the order of their presumed importance; angle of view, programed vs. unprogramed, and scaling.

In order to fully understand the derivation and use of the information presented in the matrix profiles, it is first necessary to understand the visual simulation requirements of the low altitude visual navigation

TYPE OF VEHICLE & GENERAL MISSION: ____________________

SPECIFIC MISSION SEGMENT: ____________________

EVALUATOR(S): ____________________

SIMULATION SYSTEM: ____________________

CRITICAL FACTORS	MATRIX SCORE			
	-2 -1	0	+1	+2
Scaling (3)				
Resolution				
Detail Required				
Color				
Absolute Brightness				
Contrast Range				
Distortion Tolerance				
Flicker Tolerance				
Accomodation to Infinity				
Relative Motion				
Independent Motion				
Coupled Motion				
Programmed/Unprogrammed(2)				
Angle of View (1)				
Depth Of Field				
Ease of Change				
MonocularMovement Parallax				
Interpositioning				
Physical Size				
Power Consumption				
Original Hardware Cost				
Original Software Cost				
Maintenance Cost				

Figure 23. Format of System Characteristics Profile

mission. As previously mentioned, the visual simulation requirements are derived from two sources, i.e., the characteristics of the operational environment and the perceptual requirements of the specific mission segment involved. Consideration of the above factors as they affect the simulation requirements of this mission reveals that:

a. An extremely wide angle of view is essential since many of the visual cues necessary for proper geographic orientation at low altitude are derived from the peripheral field.

b. An unprogramed (closed-loop) capability is highly desirable since the trainee must be able to exercise active control of his flight path. Whether or not this feature is essential (as opposed to desirable) is a matter of interpretation. It can be argued that since the navigation problem involves only minor deviations from a prescribed path down a defined series of terrain corridors, only a semi-programed capability is required.

c. Some form of flexible scaling is essential because the nature of the low altitude navigation mission requires large area coverage at fairly high resolution.

d. The ability to provide adequate depth cues is essential because the shallow look down angles, relatively short slant ranges, and high angular velocities characteristic of low altitude flight produce many operationally important cues which are based on interposition and on monocular movement parallax (e.g., target/terrain masking-unmasking). In this particular analysis, however, neither monocular movement parallax nor interposition were designated as critical factors because all three candidate systems are capable of meeting the requirement. Thus, although these characteristics are essential to a successful simulation of the low altitude navigation mission, it would serve no purpose to designate them as critical factors since they would not differentiate between possible engineering solutions.

In addition to the above, it should be noted that the requirement for visual information in the extreme peripheral field has implications for several other system characteristics. Thus, in an extremely wide angle display the absolute brightness, flicker tolerance, accommodation to infinity and relative motion characteristics take on added importance and, in fact, can become critical.

3.1.3.2.1 Comparison of Systems Characteristics. A comparison of the three system characteristic profiles shown in Figures 24, 25 and 26 reveals that for simulation of the low altitude visual navigation mission:

a. The CCTV-model system has two major disadvantages, viz., narrow angle of view and difficult scaling problems. In addition, it requires a relatively large and costly installation. The primary advantage

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing - Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: CCTV -Model

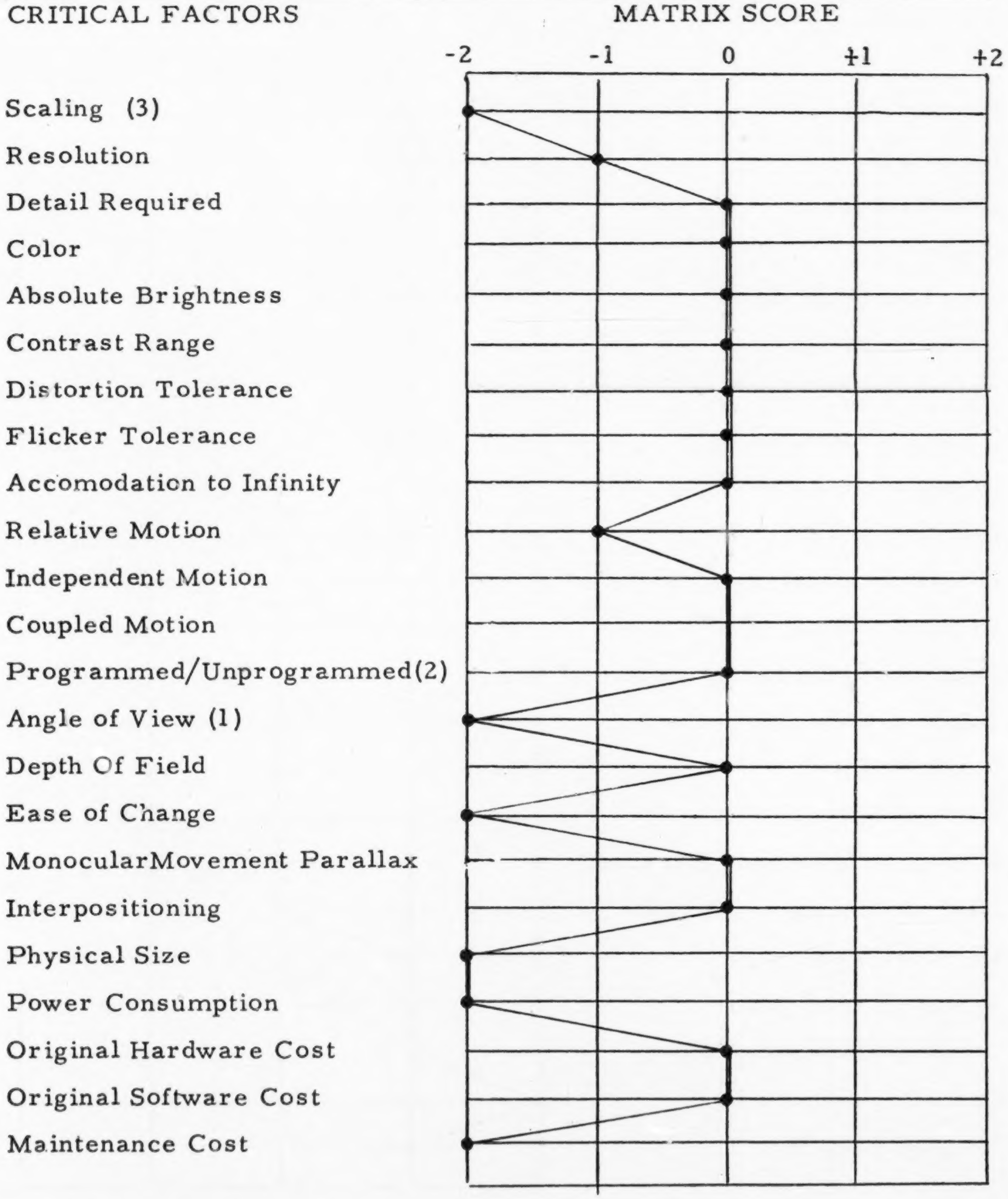

Figure 24. System Characteristics Profile for the CCTV-Model Simulation System.

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing - Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: Open Loop Movie

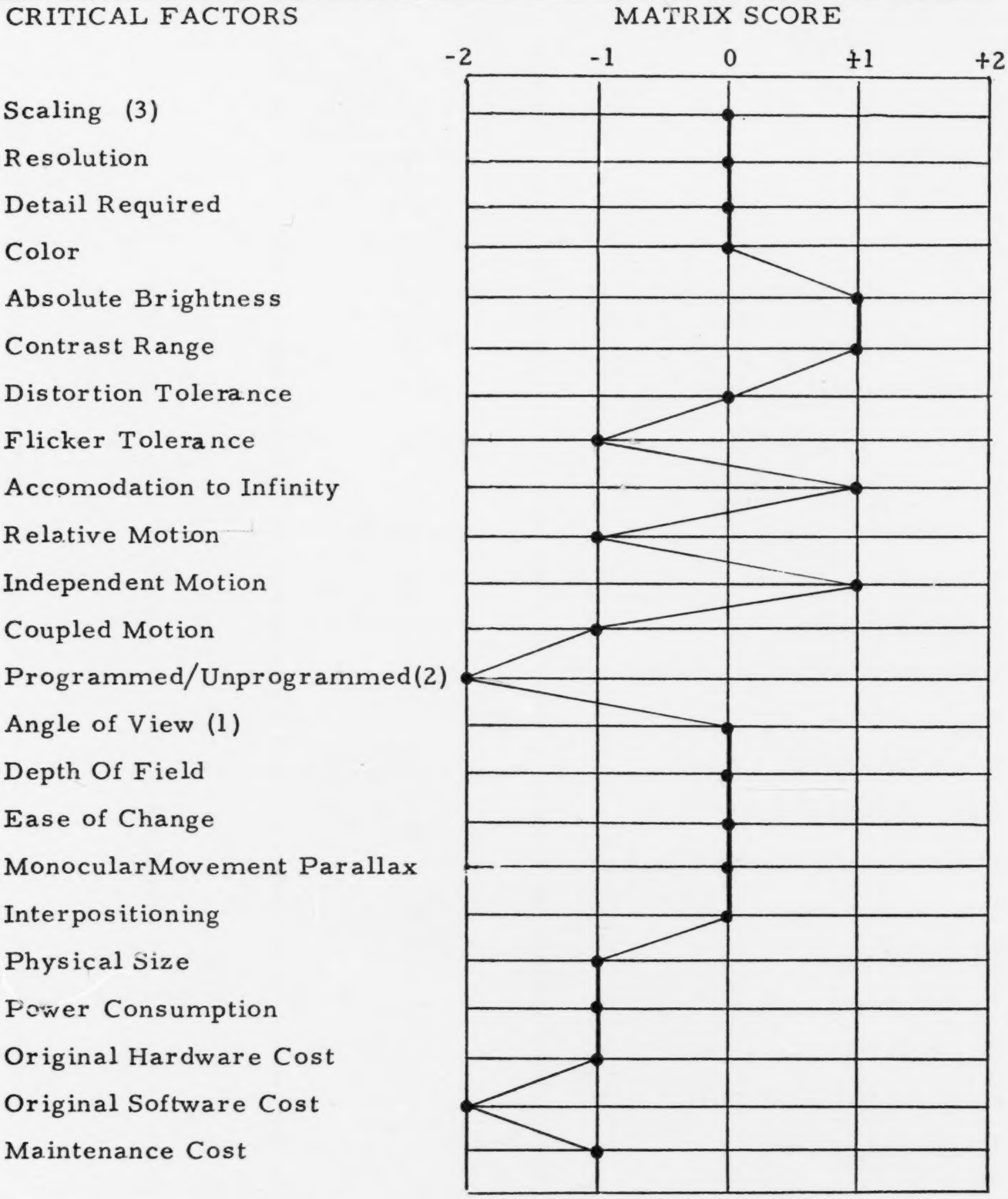

Figure 25. System Characteristic Profile for the Open Loop Movie Simulation System.

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing , Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: Computer Generated

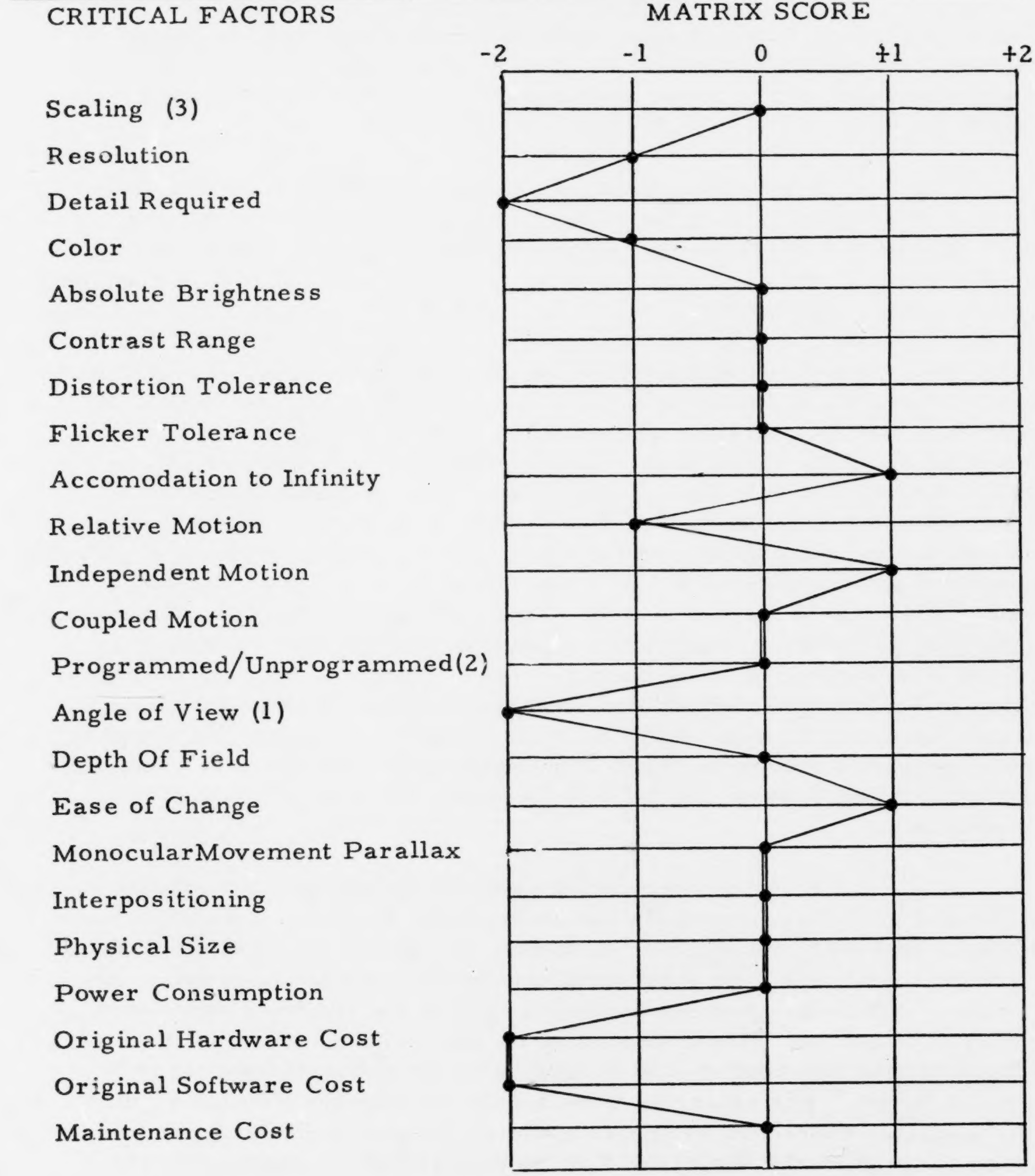

Figure 26. System Characteristics Profile for the Computer Generated Simulation System

of this type of approach is in its ability to provide unprogramed, or closed-loop operation. The profile also shows that resolution is marginal and there is an appreciable susceptibility to image smear. On the other hand, color, brightness, contrast, distortion, depth cues and original costs are considered adequate.

b. The wide angle open-loop movie system has (as its name implies) one major disadvantage, open-loop operation, and one major advantage, the ability to provide extremely wide angle imagery. Flexible scaling which presents a major problem for the CCTV-based system is an inherent property of the motion picture-based system.

Resolution, color, distortion and depth cues were all judged to be adequate. There are, however, some problems with stroboscopic effects and image smear in the extreme periphery. Size, hardware and maintenance costs are more or less moderate, but the cost of acquiring properly controlled imagery (software) is high. It should be noted here that care must be exercised in the interpretation of any matrix score shown on a profile, since any given score is the result of the interaction of simulation requirements with system characteristics. Thus, in Figure 24 both the independent motion characteristic and the ease of change characteristic are plotted as "0"s, meaning that the simulation requirement is met by the specific system characteristic in question. This is in fact true for both cases. However, the key to the effective use of this information is in the mission-derived simulation requirements. For example (refer to Figure 22), independent motion of targets within the visual field is not considered a necessary feature of the low altitude visual navigation problem. Even though the inability of the open-loop movie system to provide such motion is a primary disadvantage of the system per se, it does not constitute a disadvantage in achieving the simulation objectives of this mission. Similarly, because the ability to make small localized changes in the stored imagery is not required in this case, there is no discrepancy between the simulation requirements and system capability concerning the ease of change characteristic.

c. The computer-based imagery system is certainly the most flexible and therefore potentially the most useful of all the simulation technologies. However, its extreme flexibility is both its greatest strength and its greatest weakness. As mentioned previously, one of the greatest advantages of computer-generated imagery is that the available resolution elements ("edges" or "lines" depending on the specific technique involved) can be differentially apportioned according to the areas of interest in the visual scene. For example, in an air-to-air combat simulator, most of the available resolution elements could be devoted to defining the image of other aircraft in the visual field at the expense of ground detail, which is only needed for gross orientation. While this capability is a distinct advantage of the computed image technique, implementing it presents a major problem. In Figure 26, this is directly expressed in the detail requirement characteristic, and indirectly reflected in the high software cost factor. It will also be seen in Figure 26 that, of the system characteristics which were previously designated as critical factors, the computer-generated technique is deficient in only one, i.e., angle of view. However, the highly negative detail requirement factor should be regarded as a special disadvantage of this technique because of its influence on the values of the closely related scaling, resolution, color, depth and cost factors. Obviously, in any system based on the manipulation of a mathematically defined visual environment each element of that environment must be carefully preselected and incorporated with all of its arbitrarily assigned parameters (such as color) into the mathematical model. The precise definition of all the visual cues necessary to meet the training requirement for a given mission is often such a difficult, expensive and time-consuming task that it constitutes a major disadvantage of the approach in itself. Figure 27 illustrates the effect of individual vs. team participation in the analysis of the same simulation problem. This profile is based on the combined or team judgments of two individuals (a human factors specialist and a systems engineer) in determining the ability of the CCTV-model system to meet the simulation requirements of the low altitude navigation mission. Actually, two separate profiles are depicted in Figure 27. The solid-line profile represents the combined judgments of both individuals, while the dashed line portions of the figure show where the profile derived solely by the human factors specialist (Figure 26) differs from the combined profile. It should be noted that of the twenty three system characteristics evaluated, the individual and the team judgments were identical in nineteen cases. The four points where the analyses differ illustrate the value of team participation, in that these differences can be attributed to an increased precision in the knowledge on which the judgments are based. For example, in the team context it was pointed out that considering the nature of low altitude navigation, an unprogramed simulation capability is not essential; in fact, a semi-unprogramed approach is adequate to meet the requirement. Examination of the appropriate decision matrix of Figure 22 illustrates how this change or refinement of the simulation requirement affects the obtained matrix score. Since the system characteristic of the CCTV-model approach does not change (i.e., it is capable of providing completely unprogramed operation) the change in simulation requirement from unprogramed to semi-programed shifts the obtained matrix score from "0" to +1.

The analytic technique which has been described and illustrated here was developed to meet a specific and long-standing need, that is, the need for a logical and systematic method of organizing, displaying, and evaluating the technical information which is already available concerning the interaction of visual simulation requirements and techniques. It is, of course, recognized that the instrument described here is imperfect in many ways. However, the basic approach employed is believed to be sound and logically defensible and can and should be refined by practical use.

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing, Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude, Visual Navigation

EVALUATOR(S): Human Factors Specialist and Systems Engineer

SIMULATION SYSTEM: CCTV - Model

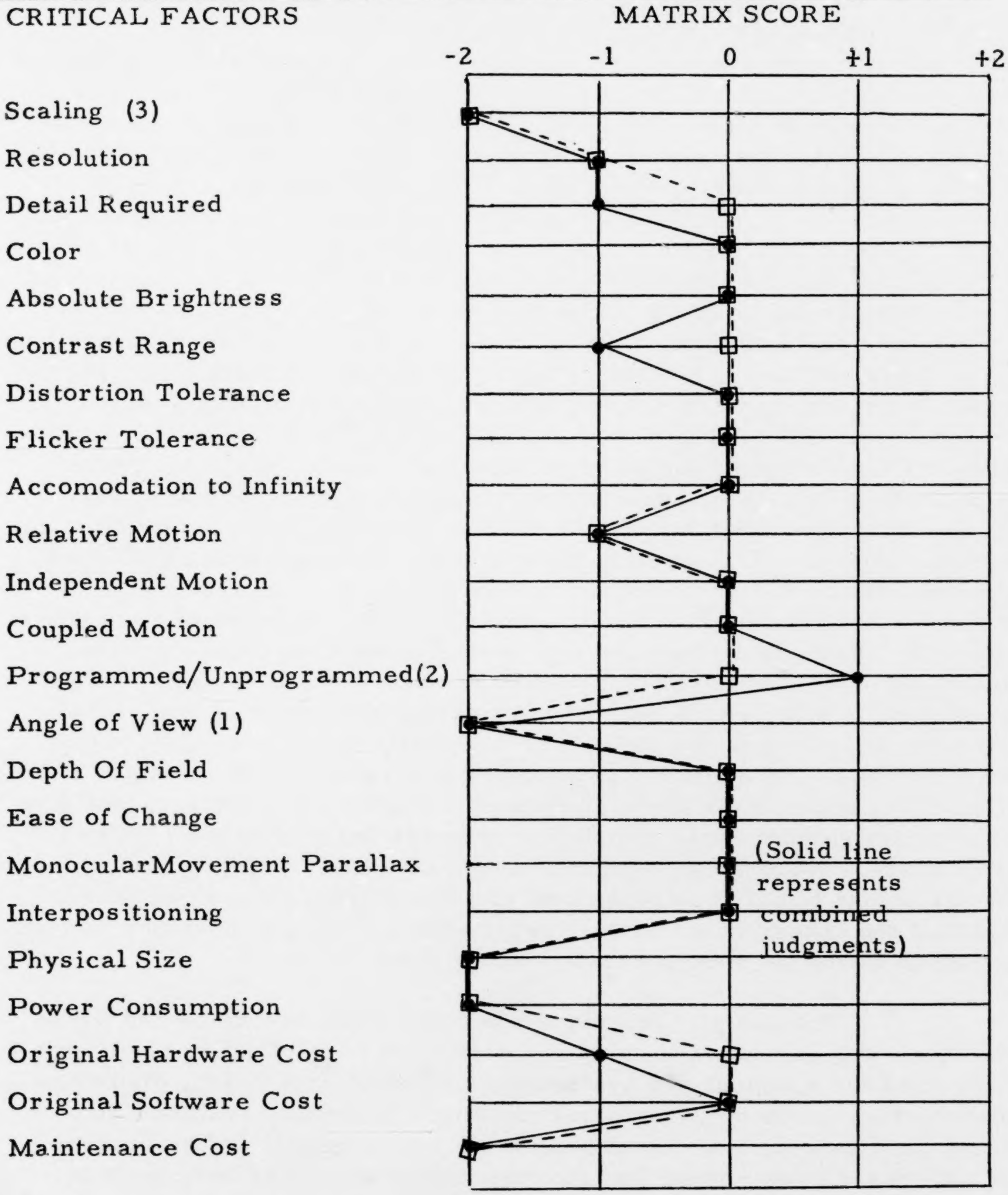

Figure 27. Team Judgments on the Ability of the CCTV Model System to Meet Simulation Requirements.

Certainly the problem to which this technique is addressed is difficult and persistent and will not be overcome without effort.

3.1.4 Research Issues.

3.1.4.1 Introduction. Research issues in the field of visual simulation may be considered to derive from two major considerations. The first consideration is that no technique recreates the real visual world in its entirety and with all its degrees of freedom. A simulation technique is selective of some part, some aspect, or some abstraction of the visual world; the simulation is less than the reality. Hence, a range of questions centers around the issues of what is lost to the human observer in one technique as compared to another technique; what are the characteristics of the image here, and what there; and so on. The second consideration is that the simulation is being made not for its own sake but as a means for training the person to perform a task involving the perception of visual imagery. Hence, there is a range of questions concerning the needful fidelity and validity of the representation and whether positive transfer of training is occurring. In most cases these two considerations are intimately linked. The simulation technique is chosen with the chief intention of providing the needed fidelity in the scene for the tasks to be trained.

The theme of the necessary incompleteness of the simulation and degree of training effectiveness underlies each of the following research issues and topics. They have been chosen on the basis that if knowledge or technique could be improved in the areas specified, more or less immediate improvements could be expected in the training effectiveness of the visual components of simulators.

3.1.4.2 Image Quality Measurement. Image quality may be defined in a variety of quantitative and qualitative ways (Soule, 1968; Luxenberg and Barnes, 1965; Ozkaptan, et al, 1969). No one of these ways seems to characterize or to predict completely the response of the human observer to the presentation. The Modulation Transfer Function (MTF) is an index of how well image details in the original are reproduced in the display. The technique is a variation of methods employed to assess and predict television and camera system performance, and in other applications. It is, by its nature, confined to assessing grey scale and contour sharpness aspects of the display. It takes no account of the content or pictorial complexity of the display. There have been various attempts to generate descriptive indices of displays. Bennett, et al (1962), took image quality in terms of resolution as the index, and while it was true that better recognition performance was associated on the average with better resolution, yet there was a very considerable variation among different targets. Ornstein, et al (1961), developed a complexity model based on the numerosity of contours, and Johnston (1968), demonstrated that it has power to predict the recognition time of targets by human observers, at least in relatively simple displays. Thus, while a good start has been made and techniques exist with some predictive capability, it is highly desirable to extend this work. An effective index of image quality would permit the accurate specification of simulator performance and permit a more rational tradeoff between the various pictorial parameters.

3.1.4.3 Vision/Motion Interaction and Cue Parity. Motion of the visual scene implies that one is moving. Increasingly, actual motion (acceleration) is being introduced into simulators to increase realism, reduce cue conflict, and in general to maintain cue parity between all the inputs impinging on the trainee. Many studies, reviewed by Rock (1966), suggest that vision is the dominant sense, and that vision tends to control the unified percept which a person arrives at concerning a scene and the events occurring to him. However, all the other senses contribute, at the least, to the perception and, when a stimulus affecting another sense is sufficiently strong, it may become the controlling input. A review of the literature reveals no studies which measure the degree of discrepancy which can occur and not be noticeable to the observer. The various falsifications which persons experience in a simulation are due sometimes, no doubt, to this lack of parity between the visual and motion cues.

Disparity occurring between the visual and motion senses has been suggested as the cause, or a contributing cause, to motion sickness experienced in a simulator. Studies are needed to measure thresholds of intersensory parity under various conditions of task and degree of motion, and to assess whether different amounts of parity are associated with sickness in the simulator.

3.1.4.4 Distortion and Cue Conflict. Visual distortion and cue conflict are present in some form in every simulation. Little is known about the relative effects of one form of distortion compared with another. Experience indicates that simple "lacks" or "absences" in a scene are not disturbing. The absence of color is acceptable; its presence adds to the scene. The absence of independent motion is acceptable; its presence adds to the scene. A narrow screen view is acceptable; a wide-screen provides a more compelling illusion. Distortion and cue conflicts, however, seem to be a common cause of user unacceptability. Optical distortion of the verticals and horizontals, poor resolution, flicker, and numerous other "artificial" visual effects have been blamed for causing simulator sickness (Puig, 1970).

Ruling out simulator sickness, there remain problems of cue distortion and conflict in terms of judgment of depth and the perception of the horizontal plane. Not all cue distortions, conflicts, or insufficiencies can be eliminated. There is a choice. Little is known concerning how to effect this choice.

3.1.4.5 Training and the Visual Parameters. There is a lack of data relating visual parameters to training effectiveness. No study was found, for instance, relating the presence of color vs. black and white to training effectiveness. There is a need for a systematic series of studies relating viewing distance, variations in resolution, brightness, contrast, field of view, color, image size, etc., to their effectiveness for training purposes. A psychological axiom is that the human can generalize and transfer his experience. But in the simulator context, we are ignorant still of whether we are overdesigning or underdesigning the training devices.

3.2 PLATFORM MOTION SIMULATION.

This chapter presents concepts and data on motion simulation pertinent to the design of ground-based training devices. The emphasis is placed on information describing acceleration and deceleration force magnitudes (i.e., rate changes) since movement, in itself, provides insufficient cues for the perception of motion. It is not any steady rate of velocity, but the change of rate of motion that man perceives. Because of the severe restrictions on the physical motion that can be incorporated into ground-based training devices, the means for achieving the acceleration cues rely in part on deceptions and subterfuge, since most devices cannot be moved efficiently more than several feet from their normal or static position. Thus, the timing and force components must occur in such ways as to encourage the trainee to react "as if" the relevant and actual aircraft motions are taking place.

The issues and data of interest to the human factors specialist in the design of training devices, are concerned with short duration acceleration forces that are meaningful in terms of perceptual thresholds, hence relying on onset and washout rates for these forces, on the scaling down of the physical forces, and on augmenting physical motion with other motion cues to achieve the desired simulation. Additional issues relate to the complexities of the acceleration force combinations required in order that the trainee accept the results as realistic since these forces affect his proprioceptive, vestibular, and tactual mechanisms differentially.

The human is incapable of differentiating components of force to which he is exposed. It is only the common resultant of the effects of various forces which he can sense. Since the force of gravity has been the predominant experience of man, the perception of the effects of gravity plays an important role in his subjective orientation in three-dimensional space. For example, when accelerative forces are added to the force of gravity so that the direction of action of the resultant force is changed with respect to the body, the sensation is that of being tilted in space (Brown, 1961).

Conversely, a number of motion issues of prime concern in the aerospace environment are of minimal importance to simulation design for training. These deal primarily with the physiological reactions to acceleration stresses, with human performance under high g (including impact) loadings and under sustained accelerations, and with the effects of excessive or sustained vibrations on human performance. Also, no emphasis is placed on physiological concomitants of motion, e.g., disorientation, nausea, coriolis effects, etc. Much research has been accomplished in military organizations on issues relevant to the perception of motion by man and on the effects of accelerative forces on human performance both in the laboratory and in the flight simulator contexts. Representative of these organizations are the National Aeronautics and Space Administration, particularly NASA Ames Research Center which has accomplished considerable research on motion employing sophisticated simulation; the Naval Air Development Center

(Johnsville, Pennsylvania); the Naval School of Aerospace Medicine (Pensacola, Florida); and the USAF School of Aerospace Medicine (Brooks Air Force Base, Texas). Considerable research data exist in the open literature. In addition to individual reports, information channels enjoying wide dissemination include such sources as the Journal of Aerospace Medicine and the Human Factors Journal. There are a sizeable number of compilations and summaries of research and application, for example, compendiums by Roth (1968), Webb (1964) and Brown (1961); books, for example, the volume edited by Burns, Chambers and Hendler (1963); and reports published by the National Academy of Science, National Research Council, for example, Human Acceleration Studies (NRC Committee on BioAstronautics, 1961).

It is not our intent to review this voluminous body of literature. Our purpose is to extract from this, concepts, data and operating practices relevant to the human factors design of training devices. Although motion simulation is a design option for a number of classes of air, surface, and subsurface vehicles, the severest challenge for human factors design is the simulation of motion representing an air vehicle. While the discussion in this section tacitly assumes a variety of vehicle classes, the concern centers on motion simulation for aircraft systems.

The ensuing presentation is organized as follows:

- An elemental review of the motion forces pertinent to the simulated environment is provided.
- A review of the literature is presented for the purpose of placing into perspective the utility of moving base simulation for training effectiveness.
- Motion requirements relative to training device design are organized.
- Specifications for the incorporation of motion into ground-based training devices are presented to the extent of the data available.
- Based on the status of the human factors technology, research issues are identified for improving knowledge and technique for design.

3.2.1 Motion Forces in the Simulated Environment. Various nomenclature is in use to describe the acceleration environment. The unit G is used to describe the physiological acceleration; the unit g defines true displacement acceleration. The physiological acceleration represents the total reactive force divided by the body mass, and hence includes both displacement and resisted gravitational acceleration effects. The physiological acceleration axes represent directions of the reactive displacements of organs and tissues with respect to the skeleton. The Z axis is down the spine, with $+G_z$ (unit vector) designations for accelerations causing the heart, etc., to displace footward (caudally). The X axis is front to back, with $+G_x$ designations for accelerations causing the heart to be displaced back toward the spine (dorsally). The X axis is right to left, with $+G_y$ designations for accelerations causing the heart to rotate (roll) to the left. Angular accelerations which cause the heart to rotate (roll) to the left within the skeleton are specified by the $+R_x$ unit vector, representing radians/sec^2 about the X axis. Angular velocities in the same sense are specified by the $+R_x$ unit vector, representing radians/sec about the X axis. Similarly $+R_y$ represents an angular acceleration producing a pitch down of the heart within the skeleton and $+R_z$ represents yaw right of the heart within the skeleton (Roth, 1968). The relationships are shown in Figure 28.

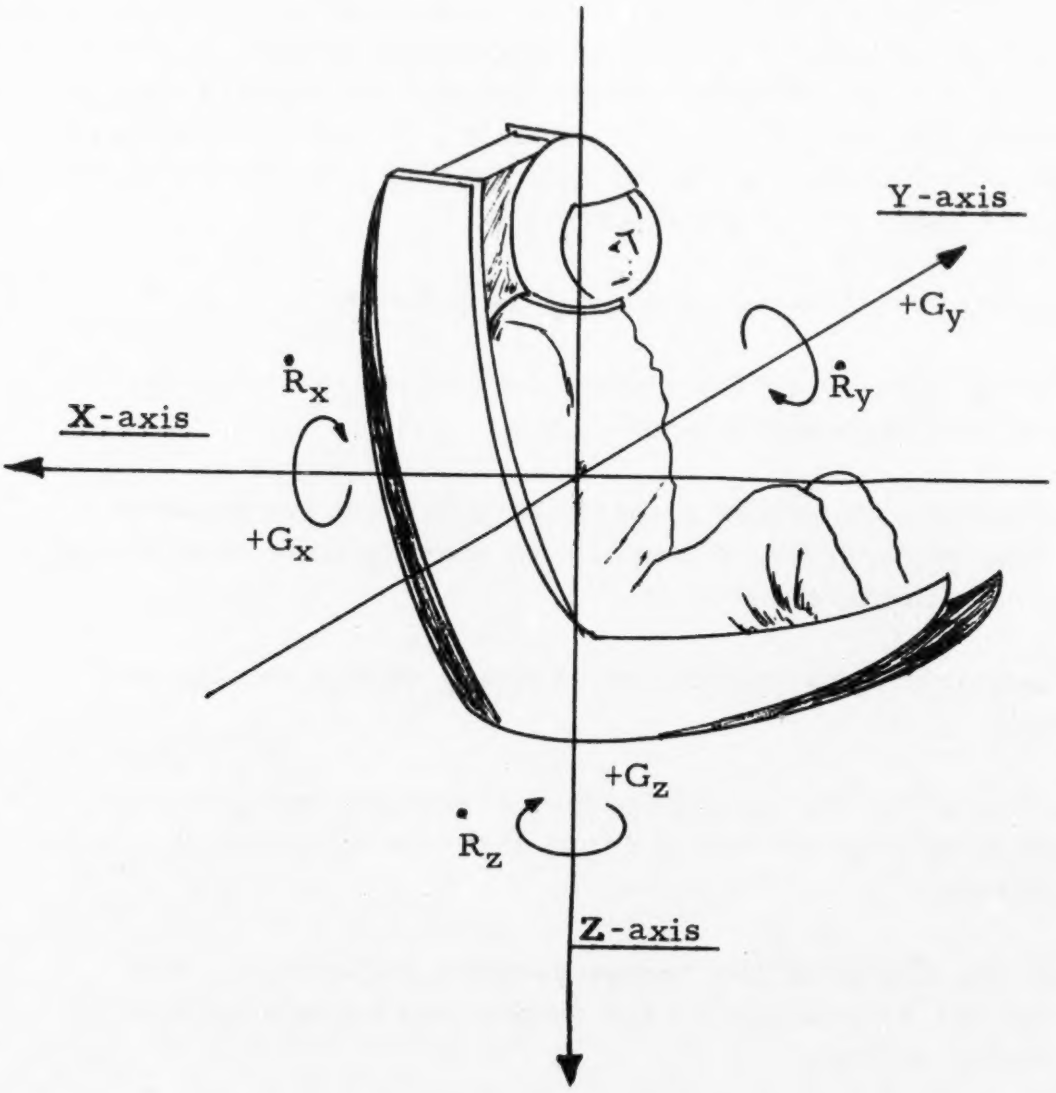

Figure 28. Physiological displacement nomenclature used in describing the physiological effects of acceleration. (from Official photograph U. S. Navy)

The nomenclature for describing vehicle displacement acceleration defines displacements in terms of three vehicular axes, X, Y and Z. These acceleration axes refer to the center of gravity of the vehicle, where X is the longitudinal axis; Y is the lateral axis; and Z is the vertical axis. The acceleration unit (g) is feet per second per second (ft/sec^2) regardless of direction.

Aircraft motions in flight, vis-a-vis the direction of acceleration, are described in terms of rotational and translational movements. These can be analyzed into six different components (i.e., degrees of motion freedom), involving movement along and around the longitudinal axis, the side-to-side axis, and the up-down axis (Figure 29). The terminology is as follows:

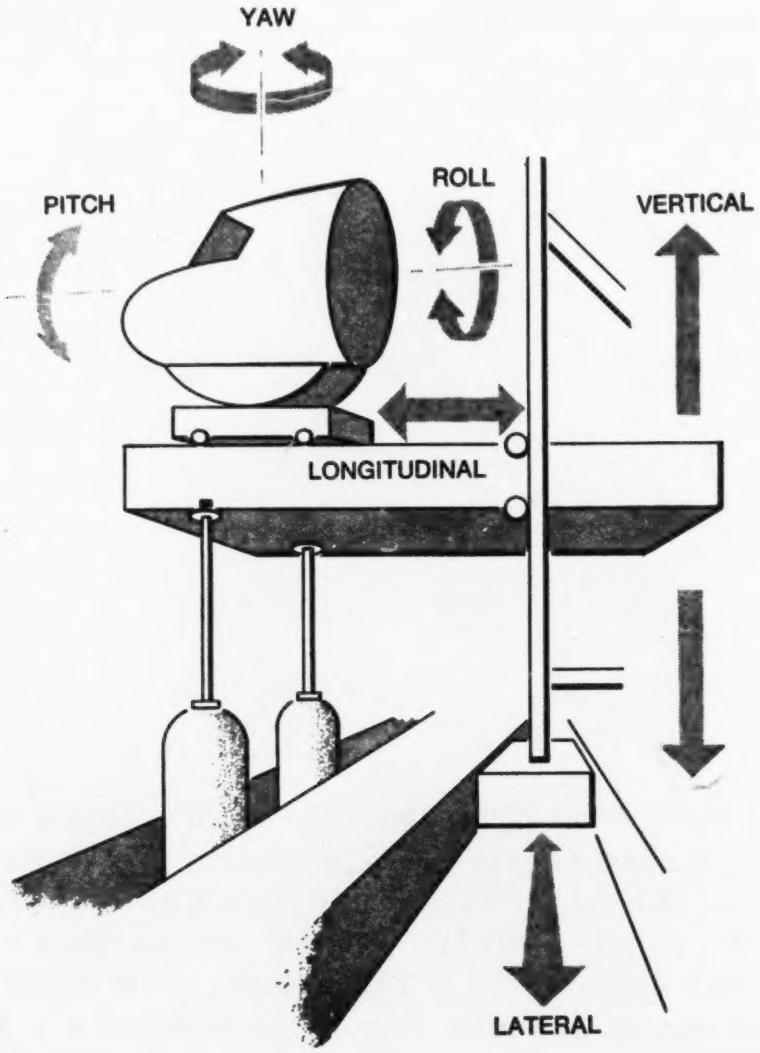

Figure 29. Simulator Motions (from NASA Ames Research Center).

rotation (angular motion)

- roll (bank about the longitudinal axis)
- pitch (nose up-down about the lateral axis)
- yaw (heading change about the vertical axis)

translation (linear motion)

- surge (fore and aft along the longitudinal axis)
- sway (side-to-side in the lateral axis)
- heave (seat to head in the vertical axis)

At any given time, the total linear acceleration of the center of gravity of the vehicle is the resultant of the three vectors of surge, sway and heave. Angular acceleration components about any given linear axis can be expressed in radians per second per second (1 rad/sec^2 equals 57.3°/sec^2), with $\dot{p}$, $\dot{g}$ and $\dot{r}$ indicating the directions of rotation.

Rotations	Translations
Roll (bank)	Surge (fore-aft)
$\dot{p}$ (about longitudinal axis)	longitudinal ($\pm G_x$)
Pitch (nose up/down)	Sway (side-side)
$\dot{q}$ (about lateral axis)	lateral ($\pm G_y$)
Yaw (heading)	Heave (seat-head)
$\dot{r}$ (about vertical axis)	vertical ($\pm G_z$)

It is reasonable to use the NASA vehicle displacement acceleration terminology in specifying human acceleration experiences (however, complete agreement on this terminology has not yet been reached, see for example, Clark, Hardy and Crosbie, 1961). Figure 30 provides a description of the vehicle acceleration environment. The equations of motion of the aircraft can be written in terms of these six vector notations. Table 18 provides a summary of acceleration nomenclature in frequent use (Chambers 1963).

3.2.2 Utility of Motion Simulation. There is ample anecdotal information and a growing experimental base of evidence that incorporating dynamic motion cues into simulators used for training produces a change in trainee behavior from that obtained with fixed base simulation. The values of proprioceptive, vestibular and tactile cues provide desired feedback to the

Nasa Airplane Axis System
(Vehicle Displacement)

LINEAR ACCELERATION MODES

Description of Aircraft Motion	*Symbol*	*Unit*
Acceleration forward (surge)	$+a_x$	ft/sec^2 or g
Deceleration (Accelerate backward)	$-a_x$	ft/sec^2 or g
Downward Acceleration	$+a_z$	ft/sec^2 or g
Upward Acceleration (heave)	$-a_z$	ft/sec^2 or g
Straight and level flight at constant speed	$a_z = 0$	
Acceleration to right (sway)	$+a_y$	ft/sec^2 or g
Acceleration to left	$-a_y$	ft/sec^2 or g

$a = a_x + a_y + a_z$

ANGULAR ACCELERATION MODES

Angular acceleration about X-axis (roll right)	$\dot{p}$	rad/sec^2
Angular acceleration about Y-axis (pitch up)	$\dot{q}$	rad/sec^2
Angular acceleration about Z-axis (yaw right)	$\dot{r}$	rad/sec^2

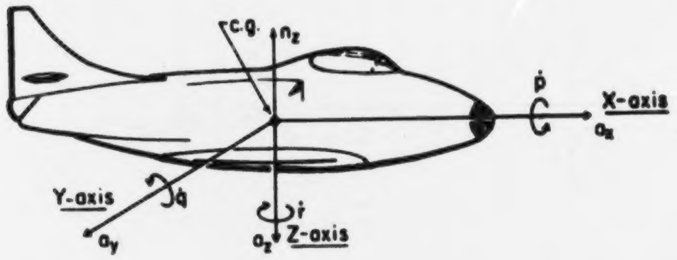

Figure 30. Description of the Vehicle Acceleration Environment. (from Clark, Hardy and Crosbie, 1961)

TABLE 18. SUMMARY OF ACCELERATION NOMENCLATURES FREQUENTLY USED.

VEHICLE DISPLACEMENT (ACTION WITH RESPECT TO VEHICLE AXES)		PHYSIOLOGICAL DISPLACEMENT (HEART REACTION WITH RESPECT TO CHEST OR SKELETON)		ACTION DISPLACEMENT (RESULTANT ACTION OF VEHICLE WITH RESPECT TO BODY)		ACCELERATION FIELD (INCLUDING BODY POSITION AND REACTIVE FORCE)	
Symbol	*Maneuver*	*Symbol*	*Response*	*Direction*	*Direction*	*G Field*	*Body Position*
$+a_x$	Catapulting or launch	$+G_x$	Heart moves towards spine	Forward	Sternumward	Transverse G	Supine
$-a_x$	Arresting	$-G_x$	Heart moves towards chest	Backward	Spineward	Transverse G	Prone
$+a_y$	Yaw right	$+G_y$	Heart moves to left	Right	Sideward, right	Lateral G	Right-to-left
$-a_y$	Yaw left	$-G_y$	Heart moves to right	Left	Sideward, left	Lateral G	Left-to-right
$+a_z$	Push over	$-G_z$	Heart moves towards head	Footward	Tailward	Negative G	Seat-to-head
$-a_z$	Pull up	$+G_z$	Heart moves towards feet	Headward	Headward	Positive G	Head-to-seat
$+\dot{p}$	Roll right	$+\dot{R}_x$	Heart rolls left	—	—	—	—
$-\dot{p}$	Roll left	$-\dot{R}_x$	Heart rolls right	—	—	—	—
$+\dot{q}$	Pitch up	$+\dot{R}_y$	Heart pitches down	—	—	—	—
$-\dot{q}$	Pitch down	$-\dot{R}_y$	Heart pitches up	—	—	—	—
$+\dot{r}$	Yaw right	$-\dot{R}_z$	Heart yaws left	—	—	—	—
$-\dot{r}$	Yaw left	$+\dot{R}_z$	Heart yaws right	—	—	—	—

(from Chambers, 1963)

trainee of vehicle status that cannot be obtained from the other senses. The acceleration sensors are continuously at work monitoring events so that an attention channel is not needed to detect accelerations. These sensors are also sensitive in detecting acceleration changes. Since acceler ation occurs prior to any velocity change, acceleration cues alert the pilot to the imminent occurrence of a motion.

A number of studies have examined the addition of motion cues in flight simulators and have compared performance with and without the motion capability. A summary of pertinent studies is presented here for the purpose of placing into perspective two questions: 1) does moving base simulation facilitate training, and 2) if the addition of motion provides training advantage, how and to what extent is this advantage manifested? Since much has been written on comparisons of fixed vs. moving base simulation, the reader is encouraged to examine collaterally a number of reports available in the literature that review, for varying purposes, the research on motion simulation. Representative of these are the reports by Graham (1968), Peters (1969), Matheny and Wilkerson (1966), Cohen (1970) and Puig (1970). A number of studies have examined the addition of motion cues in flight simulators and compared performance with and without motion. The research findings suggest that motion cues: 1) serve to alert the pilot to changing states, 2) encourage the buildup of correct habit patterns in training, 3) increase the realism of the simulation thereby enhancing trainee confidence in the device, 4) improve pilot responses, 5) affect aircraft control tasks, 6) are differentially useful as a function of the skill level of the pilot, and 7) vary in relevance (parameters and values) as a function of task or mission requirements. The essence of these findings, based on representative studies, are summarized briefly below.

Motion enhances the pilot's ability to control the aircraft. In simulated landings of an aircraft with roll disturbances, an average of about 8 seconds was required to restabilize the simulator with a moving base; about twice the time was required with a fixed base simulator (Young, 1967). The continuous motion cueing makes the pilot more aware of the requirements for, and the consequences of, control inputs and enables him to perform maneuvers more precisely and quickly (Perry and Naish, 1964). A study involving tracking in pitch during terrain contour flying in a simulator with and without motion, found that motion cues facilitated precise tracking performance (Besco, 1961).

In an early study, a 4-degree-of-freedom motion condition was compared with a no-motion condition in a Link ME-1 (T-38) jet trainer. Six experienced pilots performed a night approach and landing task with a crosswind disturbance. The visual scene was simulated by a computer-generated display of all required light patterns on a CRT monitor mounted outside the cockpit (Wendt, et al, 1961).[1] Without motion there was a (relative) tendency to undershoot the runway; however, lateral deviations were kept small. With motion, the simulated aircraft touched down significantly later; at the same time, the lateral correction was less adequate according to the automatic plotting device used to monitor objective performance. Evidently, motion alerted the pilot to certain more critical problems and caused a different allocation of his information-processing capabilities.

In situations where pilot-induced oscillations (PIO) are of concern (e.g., high performance aircraft with fully powered control systems), moving base simulation is mandatory since PIO is difficult to elicit in fixed base simulation (Rathert, Creer and Douvillier, 1959).

Simulated motion in three degrees of freedom (pitch, roll and vertical translation on the Grumman Multipurpose Simulator) provided significantly enhanced transfer to the criterion task in the simulator as compared to the performance of people trained without motion. The criterion task was described as a simulated high-speed low-altitude mission through clear air turbulence (Buckhout, et al, 1963).

Motion cues enabled pilots to perform a precise formation flight task over a range of longitudinal stability conditions better under two conditions of stick force gradients (one gradient being zero). The value of motion cues in enhancing performance compared to no motion was particularly dramatic when stick force gradients were zero (Brown, Johnson and Mungall, 1960).

A study of a simulated carrier approach and landing maneuver using the Grumman Multipurpose Simulator investigated performance under static (no cockpit motion) and kinetic (cockpit motion) conditions. Kinetic cueing during training significantly improved transfer task performance, where statically and kinetically trained groups transferred to the motion condition in the simulator (i.e., training and transfer tasks were performed in the simulator). A conclusion was that motion functions as a "general alerter" and hence serves to alert the pilot to a changing state that prompts increased attention to visual cues; in certain cases, motion may provide specifically useful information that the pilot uses directly for controlling his vehicle (Ruocco, Vitale and Benfari, 1965).

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[1] Wendt, H.W., Stark, E.A., Simon, G.B., and Cohen, E. The value of cockpit motion in flight simulation: an experimental approach. Paper read at the 69th Annual Meetings of the American Psychological Association, Session on Engineering Psychology I. New York: September, 1961.

Differences in pilot performance in simulators with and without motion cues are quite pronounced in flight under heavy turbulence conditions or for aircraft with high natural frequencies and low damping. Motion aids in the building of a response pattern which transfers positively to the aircraft. Simulator training under severe turbulence conditions is highly desirable because of the demanding and hazardous nature of the flight and because pilots do not have many opportunities for in-flight training under turbulence conditions, hence, are ill-prepared to cope with the situation. The more degrees of freedom of motion installed in the device the better the training capability since turbulence affects an aircraft in all motion dimensions.

When a sudden disturbance is applied in the simulator, the feedback loop involves the vestibular system which immediately alerts the pilot to the disturbance, although not to its exact nature. His response is to scan the instruments to detect any change. Since there will be a delay after the acceleration before the instruments show the effects of the disturbance, the pilot is primed to attend to any discernable change and apply the indicated control corrections. He is thus able to predict what is going to happen to the simulator by means of these feedback loops and hence build up habit patterns similar to those required in the aircraft. In simulators without motion, a pilot is deprived of fast acceleration feedback and so builds up simulator habit patterns which are not equivalent to those demanded in the air (Borlace, 1967).

The importance of motion cues appears to be a function of the experience level of the pilot, but whether motion in the simulator is more important for initial skill acquisition or for training pilots of some experience will depend upon the task among other things. Some data suggest that motion cues are, at least, more used and relied on as experience increases. Graham (1968) believes that motion serves as secondary cues, normally used, and improves the performance of experienced pilots since they understand the relationship of the motion to the task. Conversely, motion degrades the performance of inexperienced trainees since the motion is perceived as an unrelated distraction which hinders the control capability. The omission of motion in the simulator forces the pilot to alter his behavior from that found in the air in that he attends to the primary signal more closely, makes larger and less frequent control movements, and accepts greater error. The experienced pilot relies on associations between motion cues and responses learned in actual flight which alerts him to attend to certain instruments when certain motions are felt.

Motion cues are more closely coupled to the pilot than are visual cues. The visual sense is not as precise in sensing movement as the motion senses. Motions sensed kinesthetically act quickly and directly on the pilot. Matheny, Dougherty and Willis (1963) state that the proprioceptive senses lead the visual sense in perceiving the development of certain conditions of flight. Their data, applicable to a light, single rotor training helicopter, indicated that when the acceleration reached about $20^{\circ}/sec^2$, motion cues preceded the visual cues by a significant amount. When the angular acceleration reached approximately $25^{\circ}/sec^2$, the motion cues preceded the visual cues by .4 to .5 seconds, or the order of magnitude of one reaction time. Thus, motion cues alert and direct the attention of the pilot to changes in the aircraft enabling him to interpret displays and take action for maintaining aircraft control.

Studies at the Man-Vehicle Control Laboratory of the Massachusetts Institute of Technology (reported by Graham, 1968) indicate the following.

- In controlling a stable closed-looped system, visual information is most important. As stability is decreased, rapid detection of changes in orientation becomes more important than accuracy of alignment, and motion cues become most important.
- Motion cues assist the pilot in "taking over" following a failure in an automatic blind landing system. A nearly 100 percent deterioration (i.e., increase in recovery interval) occurred when motion cues were not available in simulation. Restabilization of the aircraft after the introduction of roll disturbances required an average of 8 seconds with moving base simulation and approximately 12-16 seconds with fixed base simulation.
- Helicopter pilots rely on motion cues for attitude stabilization. Use of motion cues appears directly proportional to pilot experience, with more skillful pilots benefiting more from motion.

Evidence from a series of studies for the Army-Navy Instrumentation Program on helicopter simulation (Feddersen, 1962) indicated that skilled pilots trained on a moving base simulator (pitch, roll, heave and yaw cues) achieved a greater rate of acquisition of proficiency and a higher level of performance (asymptote) compared to fixed base training conditions. The performance of the group initially trained on motion deteriorated when transferred to the no-motion condition; the performance of the group initially trained under no-motion improved significantly when transferred to the motion condition. Similar results (i.e., attaining greater proficiency more quickly under conditions of motion) were demonstrated by naive subjects. It was concluded that a training device incorporating the above 4 degrees of motion freedom would enhance the rate of proficiency attainment and increase the amount of transfer obtained.

Control performance is in any event different and, often, more precise with integrated visual and motion cues than with visual cues alone. The pilot receives stimuli both visually and kinesthetically, responds with an initial control action and then adjusts his response based on the feedback signals provided through the multiple sensing channels. In a study which simulated aircraft control in a side gust employing out-of-the-cockpit visual scenes with and without motion, the effect of the motion increased pilot reaction and control accuracy. Time lags for the pilot response ranged from 17 seconds with no motion cues to about 1/2 second when motion cues were available (Perry and Naish, 1964). Bristow (n.d.) concurs that motion cueing increases the pilot's response frequency and significantly improves his control accuracy at very low frequencies. The succession of motion cues makes him more aware of control input requirements and of the consequences of his responses. In Feddersen's study (1962), the pilot's control movements were high frequency and low amplitude when motion cues (yaw, heave, pitch and roll) were available, and low frequency, high amplitude in the fixed base simulator. The effects of motion cues quickened the perception of and response to error. Motion cues enabled the pilot to sense the rate of onset of a deviation, thus error was perceived proprioceptively in advance of any visual cues. In a study conducted at Douglas Aircraft Company, availability of motion cues (in a Link DC-8 simulator) enabled experienced pilots to detect simulated hydraulic brake failures quickly during the landing so that emergency brakes were operated within 1.5 to 3 seconds. With the motion system of the simulator turned off, it took the pilots more than 7 seconds to operate the braking system (cited by Cohen, 1970).

3.2.2.1 The Consensus. The considerable evidence indicates that training capability is influenced substantially by the presence of physical motion in the simulator. The consensus is that motion cues: provide significant assistance to the pilot in aircraft control; alert the pilot to changes developing in the state of the vehicle; and provide an extension of opportunity to the trainee to learn by exposing him to additional task demands. There is also some evidence that motion cues contribute to the development of habit patterns analogous to those required in actual flight.

Evidence supporting the decision to incorporate motion into the ground-based trainer is yet incomplete in terms of actual transfer benefits. The majority of the findings do not yield clear expressions of the extent of transfer of training. It is not enough to say that training value is enhanced. A practical issue is the saving in aircraft time resulting from the addition of motion cues in the simulator. Matheny and Wilkerson (1966) in reviewing Feddersen's (1962) data indicate a slight advantage for the moving base simulator. Approximately six hours in a fixed base simulator plus twenty minutes in the helicopter will produce proficiency equivalent to 4-1/2 hours in a moving base simulator with 10 minutes in the helicopter. However, the study does not accurately test the extent of the effects of motion upon transfer of training, since the two groups did not receive equal amounts of time in the trainer. The suggestion is that for beginning helicopter trainees, a proper visual display and thorough training will yield a high degree of transfer without motion. Feddersen (1961) described a study of helicopter training in which an experimental group was trained in hovering on a six degree of freedom simulator and a control group was trained under static conditions. Upon reaching an asymptote in training, each trainee was given six 2-minute hovering trials in the helicopter. The motion cue-trained group performed better initially than did the no-motion trained group but the differences disappeared by the end of the six-trial flying session. Based on this, it appears that a no-motion simulator trained group can quickly learn to use the motion cues in the aircraft (assuming relevancy with visual cues and equivalence in response dynamics between simulator and aircraft).

It appears, however, that motion simulation is desirable in providing cues and event disruption or degradation for training a variety of flight tasks.

3.2.3 Simulator Motion Requirements. Working from the evidence that the addition of physical motion enhances the training capability of simulators, the issue for human factors design is to define the nature of the motion cues to represent. The concern is for providing the needed motion cues rather than completely duplicating the spectrum of aircraft motions. To achieve motion cues that are perceptually undistinguishable from those experienced in flight vehicles is a particularly taxing requirement because of limitations in the physical displacement of the simulator, less than continuously available power and the structural stiffness of the device. Further, the requirement is predicated upon how man combines visual, somesthetic and vestibular sensations into a perception of motion and sufficient data on this integration are yet unavailable to provide a body of information than can be used effectively in human factors design. Basically, for any motion system, the specifications include the following: the degrees of freedom required, and for each motion axis, the displacement (linear, angular), and maximum acceleration required. The parameters of displacement, acceleration, and velocity are interrelated, for example, a maximum velocity attainable is limited by a given displacement and maximum acceleration.

In the following paragraphs, we will discuss the relationship of motion cues to task requirements, examine the relevant priority of the motion axes to be simulated, and describe the techniques for achieving motion cues in simulators.

3.2.3.1 Motion Cues and Task Requirements. Although the addition of physical motion in the simulator induces changes in trainee behavior, these changes may not have an appreciable effect on task performance or they may have a substantial effect on transfer. Assuming that motion cues are desirable in the training device, the question is, when are motion cues most efficiently employed and what are the parameters and combinations? Motion cues in the simulator are of value directly as a function of the type of task presented to the pilot. The performance of NASA test pilots over a wide range of steady state and oscillatory conditions under all six degrees of motion freedom indicates that motion cues are mandatory when they: 1)contribute to improved control of the vehicle, i.e., help the pilot by supplying a necessary lead or anticipation cue, as in coping with a lightly damped or unstable vehicle, and 2) interfere with satisfactory performance, i.e., hinder the pilot in making a desired control motion, as in using a powerful or a sensitive control system. (Rathert, Creer and Douvillier, 1959; Rathert, Creer and Sadoff, 1961).

3.2.3.1.1 Tasks Benefiting from Motion Inputs. Motion cues appear to be mandatory (as opposed to "nice to have") for increasing the training capability in a number of defined tasks, In these situations, the motion cues strongly influence the trainee's performance; in some situations they affect performance adversely in that greater correspondence with the operational environment is achieved resulting in increased task difficulty. In the following listing of tasks and task conditions, motion cues are regarded as mandatory for effective training:

- all tasks involving higher g forces and frequent maneuvering.

- low-altitude, high-speed flight--accelerations in terrain following maneuvers increase the relevance of the task and its difficulty level.

- pursuit tracking performance--close-coupled tracking with motion correlates more closely with actual flight under turbulent air conditions (particularly clear air turbulence penetration).

- low-altitude, high-speed flight--under heavy turbulence, aircraft instruments as well as man's motion sensors (particularly in the absence of a visual reference) provide misleading information. For example, in heavy gusts, loss of control may occur in pitch due to one or more misleading cockpit indications which call for the wrong control input.

- stability augmentation system (SAS) failure--this is a low probability event where motion (which degrades the pilot's ability to cope with the failure) will enable the pilot to make the proper responses in correcting the situation.

- control of highly sensitive or marginally stable flight vehicles--motion cues facilitate the control of these types of systems up to the point of instability, then motion interferes with pilot control and may cause loss of control.

- Non-normal landing approaches (such as carrier landings) and including abnormal conditions (such as power losses, loss of SAS, turbulence)

- V/STOL operations, particularly in takeoff and landing modes with a marginally stable vehicle.

- Pilot induced oscillations--motion cues are mandatory in order to provide training in PIO correlated with in-flight occurrences.

3.2.3.2 Priority of Motion Axes for Training. It is clear that motion requirements vary as a function of task requirements; one type of simulator is not able to represent realistically all the motions of the varieties of aircraft and missions flown. The question is, what components of motion are most needed, vis-a-vis the defined training requirements.

The consensus is that motion in the rotational axes is more useful to the pilot than motion in the translational axes. Graham (1968), interested in large jet aircraft, identifies pitch, roll and heave (vertical translation) as the most important simulator axes, followed by sway (lateral translation), yaw and surge. The next-to-last-place ranking given yaw is due to the cockpit being displaced some distance from the center of gravity, thus yaw is sensed as a sway condition. Where the cockpit is located close to the center of gravity, yaw is sensed and takes precedence over sway. When the man is near the yaw pivot point, the rotational element of yaw is an important motion axis. Surge (longitudinal acceleration) is an important fidelity consideration but difficult to simulate. As a long-term low-level acceleration it is not critical, but short-term surge (e.g., buffeting) appears mandatory for turbulence simulation and stall representation. Graham (1968) states, a moving base simulator for research purposes, "should have at least three degrees of freedom: roll, pitch and heave. A fourth degree of freedom, sway, permits the simulation of many additional flight tasks, the most noteworthy being the loss of thrust in wing-mounted engines and V/STOL approach and hover...the necessity for the remaining two: yaw and surge currently appears doubtful."(p. 24).

The inclusion of yaw and surge is supportable for a research simulator representing a wide range of aircraft types. In the simulation of small aircraft, yaw is more important than sway. Also, once four degrees of freedom are achieved, the addition of yaw and surge is more easily installed.

For helicopter simulation, pitch, roll and heave motions are desirable. Matheny and Wilkerson (1966) state:

"When one considers response to control inputs within the helicopter he finds that pitch and roll angular motions must precede the fore and aft and lateral translation motions. Thus, control over these angular motions is necessary for initiation or termination of translational motions. Further, angular accelerations about the center of gravity in general have greater magnitude and rates of onset of acceleration than do accelerations and rates of onset of the total mass of the helicopter in translation. External forcing functions such as wind gusts are also analyzed to be more disturbing to the pitching, rolling, yawing and vertical motions of the helicopter than to the fore and aft or lateral translations. If sustained, the external forcing function of a steady wind may bring the helicopter to a considerable rate of motion. However, the acceleration and rate of onset of this acceleration is felt to be generally so low that its simulation in the trainer is not necessary.

The fact that fore and aft and lateral translations are controlled through the pitch and roll dimension, and that the externally produced translational motions in fore and aft and lateral may generally be such that the visual cues will lead the proprioceptive, argues for the conclusion that the translational motions need not be simulated.

With respect to translational motion along the vertical axis, we find that this motion is controlled quite directly by movements of collective or throttle and its responses to these control inputs, as well as to external forcing functions, can be quite rapid. At the same time the visual perception of vertical motion and vertical acceleration, in particular, may be quite difficult. A second consideration argues for the inclusion of motion along the vertical axis in the trainer. In a basic trainer equipped with a visual attachment for presenting contact visual cues, a situation exists in which these cues become ambiguous and difficult for the pilot to differentiate. The visual differentiation of a change in altitude from a change in pitch, or from a fore and aft translation, is difficult for the student pilot and may even be troublesome for the experienced pilot. In the visual scene a decrease in altitude will cause an object immediately in front of the helicopter to appear to move away from it. An aft translation or pitch down will bring about an analogous movement. The question of concern is whether the addition of vertical motion to the trainer will assist in this discrimination, and our deduction is that such proprioceptive cues would be desirable in the trainer.

With respect to the rotational motions in the trainer, we have implied earlier and wish to make explicit that the pitch and roll motions are necessary to be simulated in any motion platform. Recommendations with respect to yaw motions are more difficult since, at present, they are generally more costly to incorporate into the system. On the one hand, the high degree of cross coupling between yaw and other dimensions of motion of the system and its consequent sensitivity to control inputs in other dimensions argues for its inclusion. On the other hand, the visual cues for changes in yaw, allowing as they do for a high sensitivity to disturbances in this dimension, would argue that the redundant motion cue is not necessary.

The question of simulating the motion about the vertical axis can be simplified by assuming the pivot point of the observer will be about an axis located through the planar portion of the body. With this orientation of the pivot point the only cues sensed proprioceptively will be those due to rotation (within reasonable rates of displacement). If the pivot point is shifted aft of this location, the operator may be able to sense both rotational and translational motion. ...(The) evidence indicates the visual sense may be more sensitive to rotational errors than to the proprioceptive senses. Assuming this to be the case, motion cues for yaw errors appear to be of limited value...until yaw motion simulation costs fall we must conclude that yaw motion in the light helicopter trainer is not an economical investment." (pp. 27-29).

An analysis of motion cue priority for two types of helicopters (UH-1D and CH47A) has yielded the results shown in Table 19 (Clausen, et al, 1968).

A position held by the Naval Training Device Center (Puig, 1970) is that "pitch, roll and lateral translations are considered the primary motions which should be incorporated into a motion system. Yaw motion, longitudinal surge and vertical heave should be included, cost permitting, but are generally less important. The relative importance of these motion cues will, of course, be dependent upon the aircraft characteristics being simulated. For instance, vertical heave will be extremely important in a V/STOL or helicopter simulator, whereas the lateral translations will not. In a carrier aircraft catapult simulator, longitudinal surge would assume a role of major importance; training for corrective action for engine failure would require yaw in the motion system" (p. 44).

Huddleston (1966) believes that pitch and roll accelerations and, to a lesser extent, heave acceleration are mandatory motions over a range of applications. He suggests (as hypotheses based on the research literature) the following:

a. "Yaw, sway, and surge accelerations would be progressively more difficult to justify, in terms of cost, for flight training associated with conventional lift aircraft.

TABLE 19. MOTION CUE SEQUENCE OF PRIORITY.

Motion	Control Tasks	Flight Regime	Priority	
			UH-1D	CH-47A
Pitch/Roll	Attitude Control, Translation	All Flight Regimes	1	1
Heave	Collective	Altitude Control	3	2
Yaw/ Lateral	Collective, Power Directional Control Coordination	Turns, Power Changes, Malfunctions	(Yaw) 2	(Lateral) 3
Vibration	Airspeed Control, Stall Cueing, Instrument Blurring	High Speed Flying, Power Settling	4	4

(from Clausen, et al, 1968)

b. Yaw, sway, and surge accelerations would be progressively less frequently useful in general-purpose research simulation associated with conventional lift aircraft.

c. Yaw and sway accelerations would be most frequently useful in the simulation of V/STOL and engine failure cases.

d. The more gentle flight modes (takeoff, landing, straight and level flight) can be more thoroughly treated in static simulators than the more vigorous, maneuvering modes (target chasing, terrain following, investigating boundaries of pilot acceptability).

e. Attitude control tasks are those which most demand that the simulation include cockpit dynamics, and are those which can most easily yield subversive results from static simulator work.

f. The reduction of any delays in the onset timing of cockpit accelerations in two or three axes can be more rewarding than the addition of a fourth, fifth or sixth degree of motion freedom to the cockpit.

g. A platform which unintentionally leaves the occupant more than 10 - 20° or so from the (real or apparent) vertical for more than 10 - 30 seconds or so will give rise to adverse pilot comment.

h. Spurious action cues may demand more conscious attention than meaningful cues of equal magnitude, and may detract more from subjective acceptance of a simulator than the meaningful cues can add.

i. An impression of negative g will be outstandingly difficult to produce. (Ideally, it demands that the trainee be quickly inverted at an imperceptible angular rate!)"

3.2.3.3 Sensory Thresholds for Motion Perception. The simulation of motion must be achieved by displacing the training device very short distances, but in a way that "fools" the trainee into responding as if actual aircraft motions were occurring. In recognizing these motions, the trainee is provided acceleration cues via the vestibular, proprioceptive and tactile senses. The vestibular system is the predominant motion-sensing system--the semicircular canal of the inner ear is the sensor for angular motions; the otolith is the sensor for linear accelerations, as are also the proprioceptors. Since man is sensitive to acceleration, but not to translational velocity, and since the simulator is severely constrained in the amount of travel of displacement that can be achieved, we are interested in man's acceleration perceiving capability. When does he sense the onset of various accelerations and under what conditions do these threshold values vary?

An important source of information for design comes from the research data on stimulus thresholds for the perception of motion. The perception of body motion is describable in terms of absolute and differential thresholds. These fundamental data yield information and clues on how, by synthetic means, motion perceptions can be produced indistinguishable from, or relevant to, those in flight. These data are also involved in determinations of how man combines various sensory inputs into an experience of motion. Absolute threshold data are needed to determine onset rates of motion and washout rates imperceptible to the trainee after inauguration of platform motion; differential threshold data are needed to determine ways of substituting or integrating different force components to achieve the desired motion perception.

Much work has been accomplished in this century on establishing stimulus thresholds for the perception of acceleration. As expected, the research was accomplished in a variety of contexts and for varying purposes and certain difficulties emerge in fashioning a system of values for design. The variability in the threshold data is due to a number of reasons. Various devices have been used in the studies to provide the stimulation. A number of psychophysical methods have been used in establishing the thresholds, and substantial differences exist in the definition of threshold. Considerable variation in the duration of the acceleration force and latency time is a characteristic of these studies. To this may be added the feature that the perception of motion by the human cannot be described in straightforward terms. For one thing, the sensations arising from movement stimulation of the receptors are not clear or precise. The action of the receptor mechanisms is buried in complex central nervous processes and is influenced by visual and tactile cues. Thus, obtained measurements of human thresholds are not necessarily reliable. Also, man's sensitivity is considerable, resulting in low threshold values, thus making it difficult to produce and control and to measure the accelerations at threshold levels.

The data that appear most pertinent in establishing threshold levels for the perception of motion useful to training device design are given below. Table 20 presents relevant research data on the absolute human sensory thresholds for motion as organized by Huddleston (1966). Unfortunately, some questions exist as to the accuracy of the values reported here and their sources (Wendt, 1967). There are also reservations concerning the value of these data for decisions on design parameters. The most obvious is that Table 20 presents laboratory data and the disparity between laboratory findings and operational performance is notorious. The arguments as to why this is so are well known and need not be attended to here. At best, laboratory studies tell us what the man will definitely be unable to perceive or utilize in the operational environment. Thus, the multi-stimulus situation in the operational job context and the duration and levels of characteristic task loadings indicate that the effective thresholds are raised considerably over longer time samples. Wendt[1] would raise the effective thresholds by at least a factor of two and possibly by a factor of ten or more. It might, for example, be practical to use the maximum values reported in the literature for a given threshold area (worst case assumption). Also, some data based on trials in excess of one minute are limited in relevance to simulation where thresholds are based on only a few seconds of time; (the latter are substantially higher even though the "muelder product" is apparently an oversimplification). Although laboratory data on pitch, roll and yaw thresholds are often as low as $0.1^{\circ}/\text{sec}^2$, Wendt suggests that it is more realistic to accept 0.5° to $2^{\circ}/\text{sec}^2$ as the range of concern for motion platform design. In fact, the value required for (almost) "instant detection" of angular acceleration can be estimated as near $5^{\circ}/\text{sec}^2$ or higher. (Instant detection based on exposures under about 0.5 sec duration may be a more realistic criterion for design purposes than thresholds based on many seconds or even minutes) Correspondingly, it appears

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[1] Personal communication, Dr. Hans Wendt, Macalester College, St. Paul, Minnesota.

TABLE 20. ABSOLUTE HUMAN SENSORY THRESHOLDS FOR MOTION.

Axis	Threshold	Reference
Pitch	4°/sec impulse velocity	Jones, G.M., Barry, W. & Kowalsky, N. (1964) Aerospace Med., 35: 984-989.
Roll	4°/sec impulse velocity	Jones, G.M., Barry, W. & Kowalsky, N., (1964) Aerospace Med., 35: 984-989.
	Mean 0.8°/sec impulse velocity: mode 1.6°/sec: standard range (M ± 1SD) 0.3 - 2.1°/sec	Benson, A.J., RAF Institute of Aviation Medicine, personal communication from studies on N = 51 Ss using sensation cupulometry.
Yaw	$0.035 - 4^{\circ}/\text{sec}^2$	Graybiel, A., Kerr, W.A., & Bartley, S.H., (1948), Am. J. Psychol., 61: 21.
	$0.12 - 0.17^{\circ}/\text{sec}^2$	Clark, B., & Stewart, J.D., (1962), Aerospace Med., 33: 1426-1432.
	$0.2 - 0.5^{\circ}/\text{sec}^2$	Johnson, J.L., (1959), WADC-TN-58-314, Supp. 1.
	$0.28 - 2.0^{\circ}/\text{sec}^2$ (mean 0.5)	Groon, J.J., & Jongkees, L.B.W., (1948), J. Physiol., 107: 1-7.
	Down to $0.2^{\circ}/\text{sec}^2$	Tumarkin, I.A., (1937), Proc. R. Soc. Med., 30: 599-610.
	4°/sec impulse velocity	Jones, G.M., Barry, W., & Kowalsky, N., (1964), Aerospace Med., 35: 984-989.
	$0.06 - 0.035^{\circ}/\text{sec}^2$	Mann, C.W., & Ray, J., (1956) USN School of Aerospace Med., NM-001-110-500-41.
	Mean 0.9°/sec impulse velocity; mode 1.6°/sec; standard range (M±1SD) 0.3 - 1.7°/sec.	Benson, A.J., RAF Institute of Aviation Medicine, personal communication from studies on N = 103 Ss, using sensation cupulometry.

TABLE 20. ABSOLUTE HUMAN SENSORY THRESHOLDS FOR MOTION (Continued).

Axis	Threshold	Reference
Heave	1.7 - 4.0 cm/sec^2	Gurnee, H., (1934), J. Exp. Psychol., 17: 270-285.
	1 - 5 cm/sec^2 prone or supine	Walsh, E.G., (1961), J. Physiol., 155: 506-513.
	4 - 12 cm/sec^2	Fogel, L.J., (1963), Biotechnology, p. 151, Prentice-Hall, Englewood Cliffs, N.J.
	6 - 15 cm/sec^2 prone or supine	Jongkees, L.B.W., & Green, J. J., (1946), J. Laryngol, 61: 529-541.
	0.003 - .02g, dependent on frequency, for sinusoids 1.5 - 50 c/s (lowest 3 - 6 c/s, highest 15 - 50 c/s)	Goldman, D.E., (1948), US NMRI, MI-004-001-1.
	.009 - .05g, dependent on frequency, for sinusoids 3 - 30 c/s (lowest 8 - 9 and 13 - 18 c/s, highest 3 - 7 c/s)	Gorrill, R.B., & Snyder, F.W., (1957), Boeing Co. D3-1189.
	.002 - 1.0g, dependent on frequency, for sinusoids 1 - 27 c/s (lowest 1 - 9 c/s, highest 9 - 22 c/s)	Parks, D.L., & Snyder, F.W., (1961), Boeing Co. D3-3512-1.
	Approx. linear from 0.5 cm/sec^2 at 0.5 c/s to 20 cm/sec^2 at 100 c/s, sinusoids	Dieckmann, D., (1958), Ergonomics, 1: 347-355.
Sway	1 - 3 cm/sec^2 prone or supine	Walsh, E.G., (1961), J. Physiol., 155, 506-513.
	12 - 20 cm/sec^2	Fogel, L.J., (1963), Biotechnology, p. 151, Prentice-Hall, Englewood Cliffs, N.J.

TABLE 20. ABSOLUTE HUMAN SENSORY THRESHOLDS FOR MOTION (Continued).

Axis	Threshold	Reference
Sway	Linear from 0.003 cm double amplitude at 4 c/s to 0.0003 cm at 40 c/s, for sinusoids, supine	Reiher, H., & Meister, F.J., (1931), Forsch., 2: 381-386, Berlin.
Surge	12 - 20 cm/sec^2	Fogel, L.J., (1963), Biotechnology, p. 151, Prentice-Hall, Englewood Cliffs, N.J.
	0.5 - 1.3 cm/sec^2, dependent on frequency, for sinusoids 0.5 - 10 c/s (lowest at 3 - 5 c/s, highest at 8 - 10 c/s)	Ishimoto, M. (1932), Bull. Earthquake Res. Inst., Vol. 10, Tokyo.
	0.6 - 2.0 cm/sec^2, dependent on frequency, for sinusoids 0.4 - 10 c/s (lowest at 1 - 4 c/s, highest at 6 - 10 c/s)	Ishimoto, M., Ootsuka, O., (1933), Bull. Earthquake Res. Inst., Vol. 11, Tokyo.
	Linear from 0.002 cm/sec^2 double amplitude at 5 c/s to 0.0002 cm/sec^2 at 60 c/s for sinusoids	Reiher, H., & Meister, F.J., (1931), Forsch, 2: 381-386, Berlin.
	Approx. linear from 0.2 cm/sec^2 at 0.2 c/s to 10 cm/sec^2 at 50 c/s, for sinusoids	Dieckmann, D., (1958), Ergonomics, 1: 347-355.

(from Huddleston, 1966)

justified to use values such as 0.3°/sec^2 as in effect, "subliminal" since also, fadeback accelerations compatible with this value have been found practical by a manufacturer of simulation equipment.

Huddleston lists heave, sway and surge thresholds in a range of 0.5 to 20 cm/sec^2 (corresponding to approximately 0.0005 to 0.02 g). Wendt feels these values are rare and points to other studies where values up to 0.08 g or higher were obtained. The range of values reported differ by about two orders of magnitude (which is not uncommon in attempts to determine thresholds). For operational environments, Wendt recommends linear accelerations in excess of about 0.1 g if reliable cue value is essential.

Clark (1967) has also summarized a number of studies which report stimulus thresholds for the perception of angular acceleration. Table 21 presents his summary.

The stimulus thresholds reported for angular accelerations vary considerably between 0.035°/sec^2 and 8.2°/sec^2 with a median around 1.0°/sec^2. Thresholds are lower about the yaw axis than about the pitch and roll axes. Clark and Stewart (1962) in the study of pilot perception of angular acceleration about the yaw axis at NASA Ames Research Center, obtained values as low as 0.13°/sec^2 for latency times of 8-14 seconds; and about 1°/sec^2 for a latency time of 2 seconds. For mean reaction latency times of from 0.5 to 1.0 seconds the acceleration threshold was 10.0°/sec^2. Doty (1969), working in the same laboratory, measured 0.1°/sec^2 for 6 seconds stimulus duration.

The highest value (about the pitch axis) was obtained from a pilot operating a Link Trainer (Sadoff, Matteson and Havill, 1955). The great variation in values is to be expected, considering the types of tasks involved, the definitions of threshold used and the duration of the angular accelerations employed (from less than a second to more than a minute). Direct comparisons among studies are hampered in particular by the variations in duration of acceleration. It was once believed that, uniformly, acceleration X time = a constant within certain limits, at or near the threshold (the "Muelder product") (Muelder, 1908; Van Egmond, et al, 1949). The product, according to some experiments, increases for both longer and shorter time durations. However, certain earlier assumptions underlying the use of the Muelder product (cf. Muelder, 1908) are not as generally valid as once thought. For example, in a recent study by Doty (1969) the oculogyral illusion was used to test the reliability of the integration phenomenon that is ordinarily postulated. The illusion in question tends to be very stable across and within individuals, and is probably the most sensitive indicator among several that can be used to measure thresholds for angular acceleration. In the Doty study, average thresholds were low, ranging from 0.10°/sec^2 to 0.62°/sec^2 depending on stimulus duration. However,

TABLE 21. Thresholds for the Perception of Stimulation by Angular Acceleration in Man.

Author & Date	Van Wulfften Palthe[63] 1922	Dodge[14] 1923	Tumarkin[59] 1937	Christian[5] 1939	Christian[5] 1939	Clark, Graybiel & MacCorquodale[8] 1948	Clark, Graybiel & MacCorquodale[7] 1948
Threshold	$\sim 2^{\circ}/\text{sec}^2$	1°-2°/sec	$0.2^{\circ}/\text{sec}^2$	0.13°-$0.33^{\circ}/\text{sec}^2$	0.13°-$2.0^{\circ}/\text{sec}^2$	$\sim 18^{\circ}$ bank	$\sim 0.2^{\circ}/\text{sec}^2$ $\sim 18^{\circ}$ of bank
Indicator response a) Perceptual mode	Rotation	Rotation	Rotation	Oculogyral illusion	Rotation	Oculogyral illusion	Oculogyral illusion
b) Method of response	Forced-choice	Forced-choice	Yes-No	---	---	Forced-choice	Forced-choice
Canals stimulated	Horizontal & vertical	Horizontal & vertical	Horizontal & vertical	Horizontal & vertical	Horizontal & vertical	Horizontal & vertical	Horizontal & vertical
Head position	Erect	Erect (?)	Erect	Erect (?)	Erect (?)	Erect in cockpit	Erect in cockpit
Stimulus a) Duration	Not reported	"Sudden onset"	Variable	---	---	9-14 sec	11-28 sec
b) Determination of angular acceleration	Computed	Not determined	Computed	Computed (?)	Computed (?)	Not determined	Computed
c) Method of presentation	Constant stimuli	Constant stimuli	Ramp acceleration	---	---	Constant stimuli	Constant stimuli
Subjects	4	5	5(?)	---	---	4	3
Rotation device	Spyker aircraft	Rotating chair	Rotation in water	Rotating chair	Rotating chair	SNJ-6 aircraft	SNJ-6 aircraft
Definition of threshold	50% above chance report	50% point	Point at which movement perceived	---	---	50% level corrected for guessing	50% above chance

Author & Date	Graybiel, Kerr & Bartley[25] 1948	Groen & Jongkees[27] 1948	Groen & Jongkees[27] 1948	MacCorquodale[41] 1948	de Vries[60] 1949	Hallpike, Hood & Byford[35] 1952	Hallpike & Hood[34] 1953
Threshold	$\sim 0.12^{\circ}/\text{sec}^2$	0.28°-$2.0^{\circ}/\text{sec}^2$	0.18°-$0.25^{\circ}/\text{sec}^2$	0.10°-$0.15^{\circ}/\text{sec}^2$ 15° of bank	0.9°-$4.0^{\circ}/\text{sec}^2$	0.2°-$1.0^{\circ}/\text{sec}^2$	0.2°-$0.7^{\circ}/\text{sec}^2$
Indicator response a) Perceptual mode	Oculogyral illusion	Rotation	Rotation	Rotation of aircraft	Rotation	Rotation	Oculogyral illusion
b) Method of response	Forced-choice	---	---	Forced-choice	Yes-No	---	Forced-choice (?)
Canals stimulated	Horizontal	Horizontal	Horizontal	Horizontal & vertical	Horizontal	Horizontal	Horizontal
Head position	20°-25° forward	Head forward	Head forward	Erect in cockpit	Head 30° forward	Head 30° forward	Head 30° forward
Stimulus a) Duration	Varied	~30 sec	Varied	Varied	0.1-1.0 sec	---	15-150 sec
b) Determination of angular acceleration	Computed	Computed	Computed	Computed	Computed average	Computed from oscillograph	Computed
c) Method of presentation	Constant stimuli	---	---	Constant stimuli	Constant stimuli	---	Constant stimuli
Subjects	5	30	2	3	1	5	3
Rotation device	Centrifuge	Rotating chair	Torsion swing	SNJ-6 aircraft	Rotating chair	Rotating chair	Rotating chair
Definition of threshold	50% above chance level on frequency ogive	---	Formula including damping of cupula-endolymph system	50% above chance identification	Number of stimuli perceived corrected for guessing	---	---

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TABLE 21. Thresholds for the Perception of Stimulation by Angular Acceleration in Man (continued).

Author & Date	Hallpike & Hood[34] 1953	Hilding[38] 1953	deVries & Schierbeek[61] 1953	Sadoff, Matteson & Havill[55] 1955	Mann & Ray[44] 1956	Montandon & Russback[49] 1956
Threshold	0.6°-2 0°/sec²	0.25°-3.0°/sec²	0.9°-1.7°/sec²	5.3°-8.2°/sec²	0.035°-0.13°/sec²	0.5°-1.0°/sec²
Indicator response						
a) Perceptual mode	Rotation	Rotation	Rotation	Pitch-up of simulator	Rotation	Rotation
b) Method of response	Forced-choice (?)	Forced-choice	Yes-No	Yes-No	Forced-choice	Forced-choice (?)
Canals stimulated	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Horizontal
Head position	Head 30° forward	Head 30° forward	Head 30° forward	Head erect	Head about 15° forward	Erect (?)
Stimulus						
a) Duration	15-150 sec	Varied	0.4 sec	Varied	4-30 sec	Varied
b) Determination of angular acceleration	Computed	Computed (?)	Computed	Computed	Computed	Computed
c) Method of presentation	Constant stimuli	Increasing steps of angular acceleration	Constant stimuli	Ramp acceleration	Up & down time varied	"Liminal"
Subjects	3	26	3	4	4	?
Rotation device	Rotating chair	Rotating chair	Rotating chair	Link trainer	Rotating chair	Rotating chair
Definition of threshold	---	---	75% point with deVries' correction for guessing	Point on graph of increasing acceleration corrected for RT	75% correct identification	---

Author & Date	Roggeven & Nijhoff[54] 1956	Roggeveen & Nijhoff[54] 1956	Clark & Stewart[9] 1962	Von Diringshofen, Kissel & Osypka[12] 1964	Miery[47] 1965	Miery[47] 1965
Threshold	1.3°/sec²	1.8/sec²	0.12°-0.17°/sec²	0.26°-1.0/sec²	0.1°-0.2°/sec²	0.5°/sec²
Indicator response						
a) Perceptual mode	Oculogyral illusion	Rotation	Rotation	Rotation	Rotation	Rotation
b) Method of response	Yes-No	Yes-No	Forced-choice	Forced-choice	Forced-choice	Forced-choice
Canals stimulated	Horizontal	Horizontal	Horizontal & vertical	Horizontal	Horizontal & vertical	Horizontal & vertical
Head position	Head 30° forward	Head 30° forward	Head erect in cockpit	"Slightly bent forward"	Head erect	Nose down
Stimulus						
a) Duration	0.8 sec	0.8 sec	10 sec	Varied	Varied	Varied
b) Determination of angular acceleration	Computed	Computed	Angular accelerometer	Computed	Computed	Computed
c) Method of presentation	Constant stimuli	Constant stimuli	Constant stimuli	Ramp acceleration	Constant stimuli	Constant stimuli
Subjects	15	15	5	9	3	3
Rotation device	Rotating chair	Rotating chair	Flight simulator	Flight simulator	Flight simulator	Flight simulator
Definition of threshold	50% correct indication corrected for guessing	50% correct indication corrected for guessing	75% correct identification	Point at which movement perceived corrected for RT	75% correct identification	75% correct identification

(From Clark, 1967)

the acceleration x time products were not constant. Rather, they ranged from approximately 0.3°/sec (measured for a stimulus duration of 0.5 sec) to approximately 0.6°/sec, the latter measured at 6.0 sec duration of exposure. Graphic extrapolation of these data leads to about 0.8°/sec as an estimate of the acceleration x time product near stimulus durations of 10 sec, etc. In other words, while the function appears to be a linear one, the slope is not zero, but is significantly positive.

A summary of the results of laboratory data on determining thresholds for angular acceleration is shown in Figure 31. The data show that man relates angular acceleration to reaction latency (time). For very low angular acceleration the time lag prior to detection is significant, e.g., for accelrations of 0.05 to 0.1°/sec^2 there is a substantial lag (8 - 10 seconds) in sensing acceleration. For accelerations in excess of 10°/sec^2, the latency is on the order of 1/2 second prior to detection. Figure 32 provides threshold data on linear acceleration.

Wendt (1966) in a review of the literature on threshold values has selected excerpts relevant to the design of moving base simulators. Among his conclusions are the following:

- There is evidence that sensitivity is greatest for rotation around the pitch axis, less marked for the yaw axis and least for the roll axis. The differentials, however, appear to be too small to serve as useful guidelines for design.

- Natural or frequently experienced cue levels are of value in that a pilot knows what certain g values feel like and these should be emphasized in that they may serve as a frame of reference for motion even though other g levels are not simulated with similar fidelity. One such well-known standard criterion is the self-imposed vertical accelerations arising from stooping, standing up from the seated position, etc. This component ranges from 0.03 to 0.40 g with a mean of 0.15 (measured on military populations). Thus, a pilot not familiar with the aircraft may conceivably be able to compare certain accelerations with those familiar to him.

- The direction of linear acceleration can be accurately discriminated for values of >10 cm/sec^2 when force is alternately applied in opposite directions. This corresponds to >0.01 g and is lower than values obtained when simple linear accelerations are discriminated from zero.

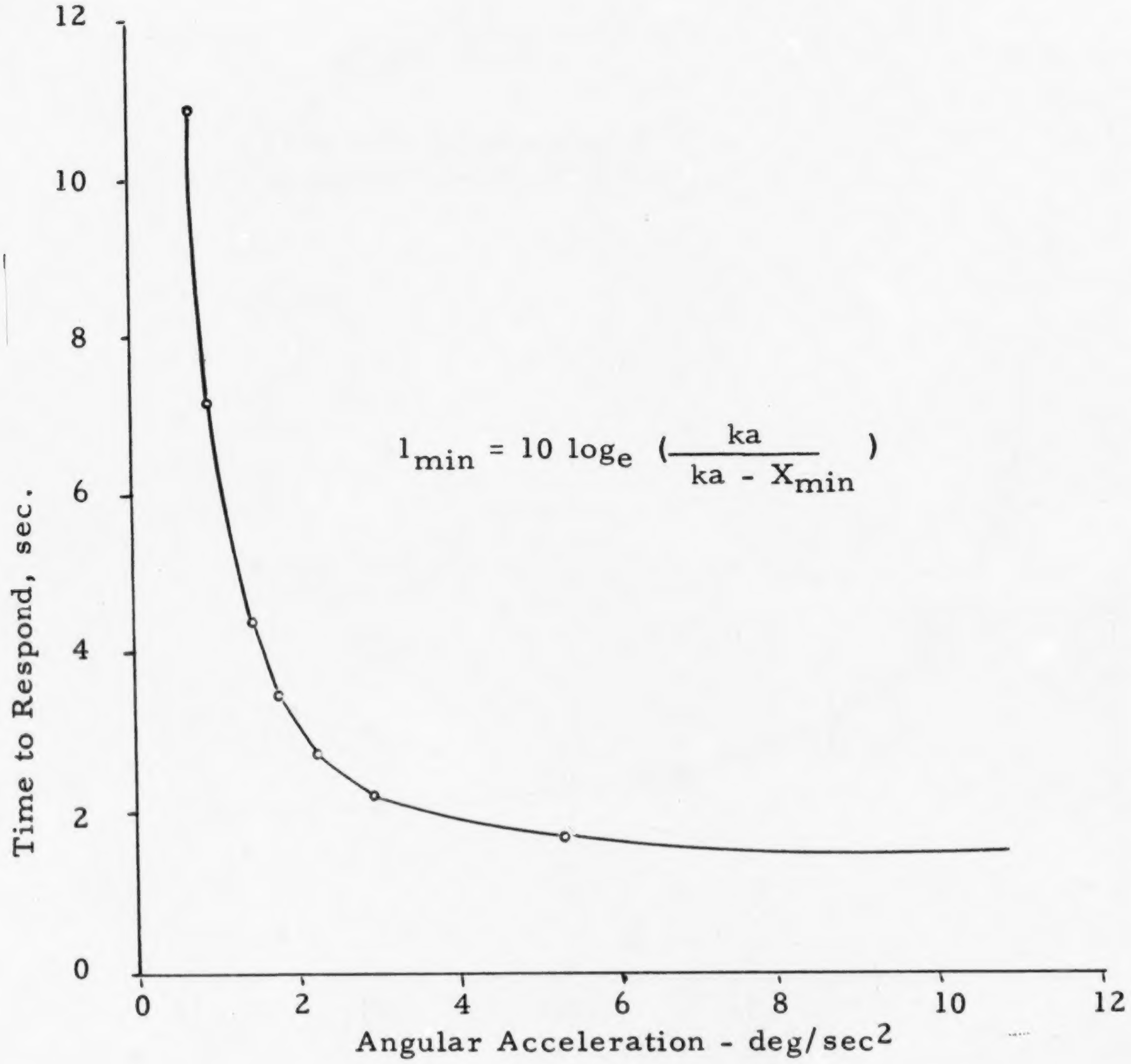


Figure 31. Threshold for sensing rotation.

(from Clausen, et al, 1968; based on data from Meiry, 1965)

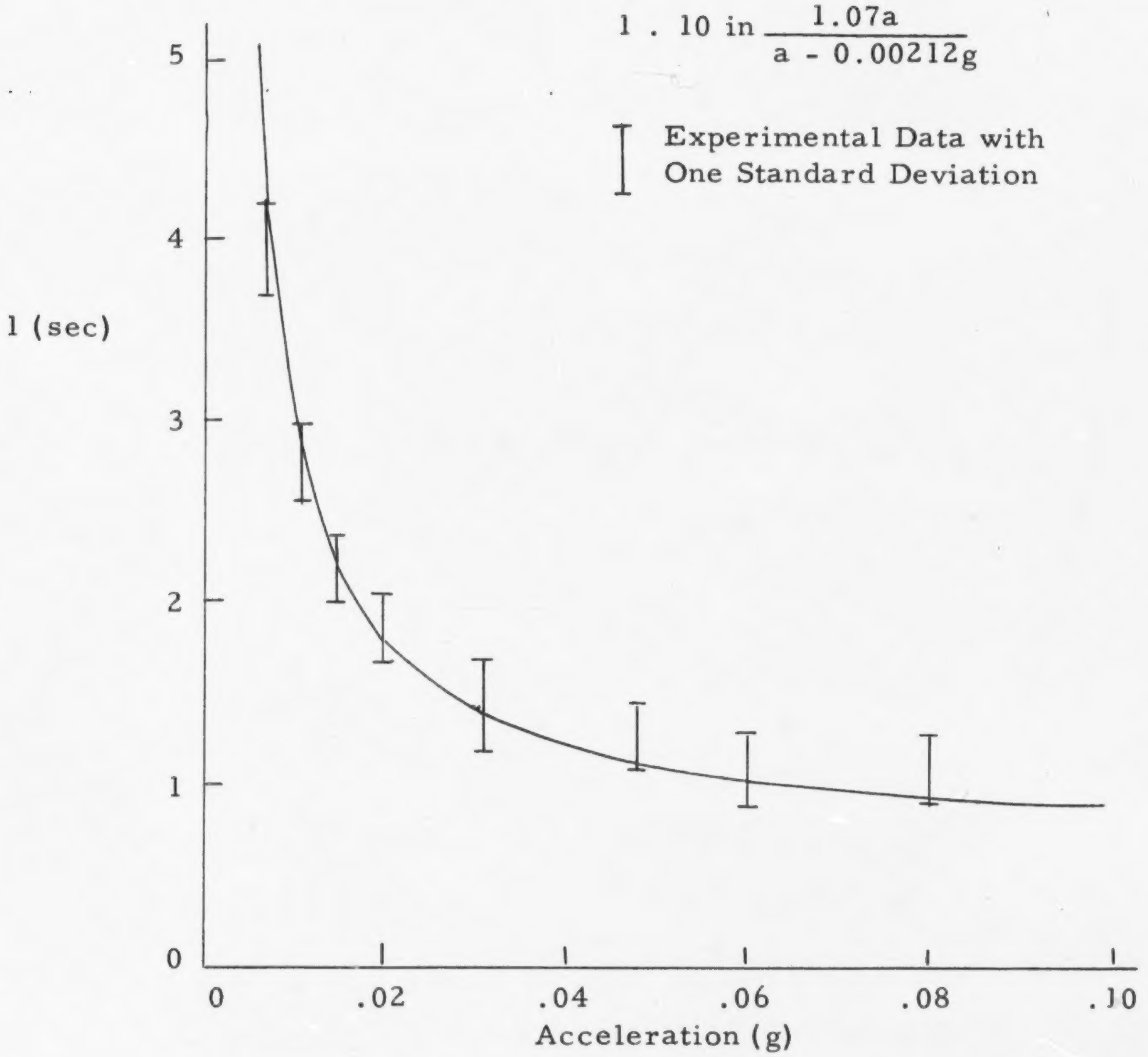


Figure 32. Latency times for perception of acceleration along the sagittal axis with the head upright.

(from Clausen, et al, 1968; based on data from Meiry, 1965)

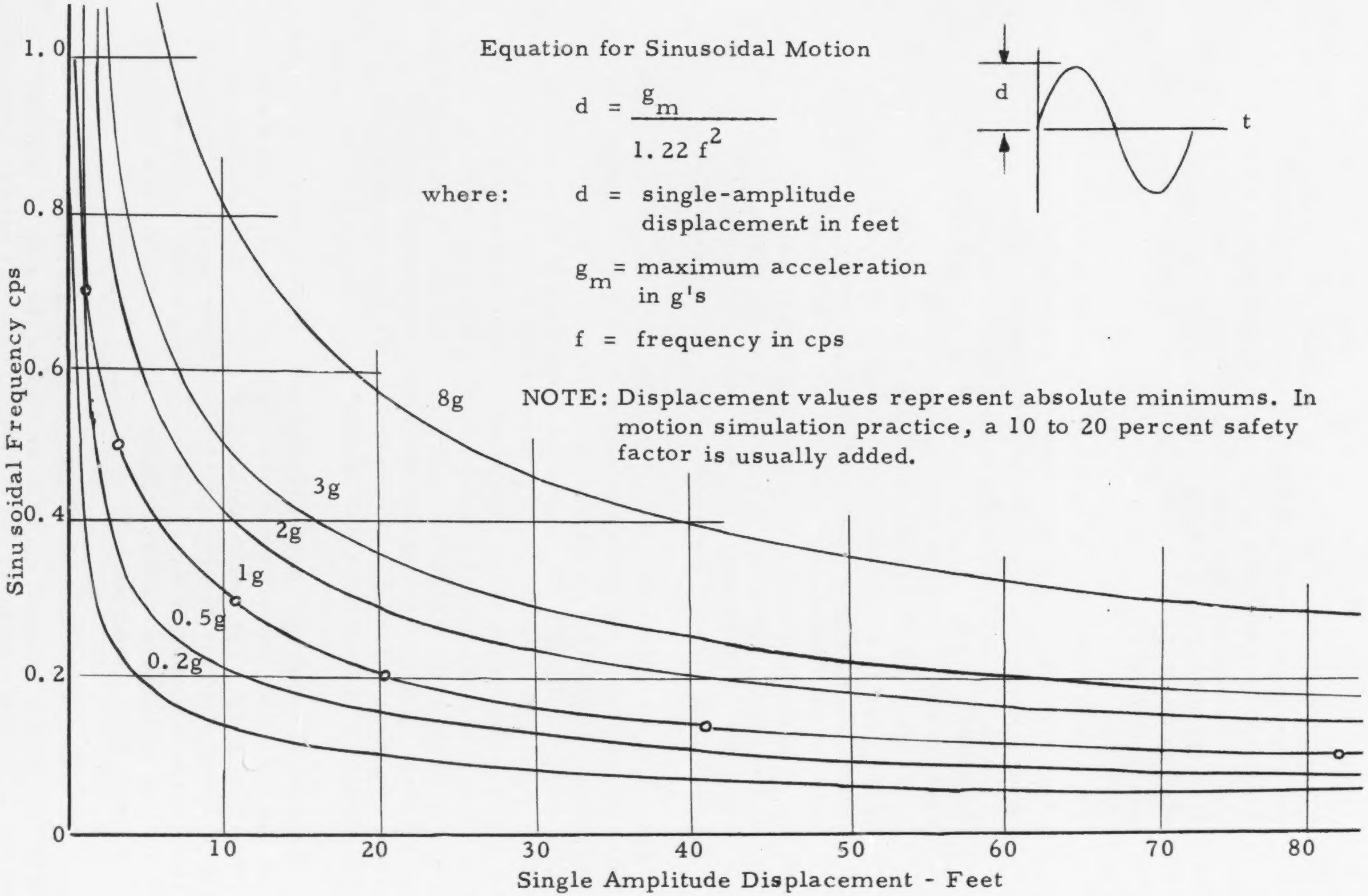
- Vertical motion can be used to simulate pitch when the pivot point is some distance from the man (e.g., 30 feet behind and where the vertical position of the cab is washed out to its starting position). Vertical displacement with washout is more satisfactory than scaling down the pitch axis distance by factors varying from 2 to 5.

- Angular acceleration thresholds--laboratory data range from $0.2^\circ/\text{sec}^2$ to $2.0^\circ/\text{sec}^2$ (assuming long latency periods). When response latency is the criterion, about 2 seconds are required to detect $3.0^\circ/\text{sec}^2$; 3 seconds are required to detect $2.0^\circ/\text{sec}^2$; nearly 7 seconds are required to detect $1.0^\circ/\text{sec}^2$. In terms of short time duration, as is the case in simulation, man is relatively insensitive to changes in angular motion in the absence of other cues. Some data suggest that, if the maximum permitted response latency is held to about 1.5 seconds, and if latency is taken as the chief criterion of threshold, then the average observer cannot tell $4^\circ/\text{sec}^2$ from 10° - $15^\circ/\text{sec}^2$ accelerations.

3.2.3.4 Achieving Acceleration Cues in Simulation. The physical displacement limitations places serious constraints on both acceleration and frequency response. Displacement varies inversely as the square of the frequency for sinusoidal motion; the higher the frequency of the acceleration the smaller the displacement. As frequencies fall below one cycle per second for a given acceleration level, displacement requirements increase considerably. For example, an acceleration of ± 1g at 1 cps requires ±10 inches displacement while an acceleration of ± 1g at 0.1 cps requires ±85 feet (Graham, 1968). A plot of frequency vs. displacement for various accelerations is shown in Figure 33. Representing the low frequency or sustained accelerations is particularly difficult.

Because of the displacement limitations, techniques are required for deceiving the human by providing cues that have signal value and have relevance (meaning) to the real world counterpart. Several techniques of simulating g forces are currently practiced in simulator design. These are: the use of onset cues and washout acceleration; scaling of acceleration; and the use of signaling techniques such as inflatable seat cushions and seat belt tighteners. Each is discussed below.

3.2.3.4.1 Acceleration Onset and Washout. Acceleration and discrimination of differences in accelerations is a function of the rate of onset of acceleration (jerk or jolt). Matheny, et al, (1963) hold that rate of onset may be more of a direct cue than any absolute value of acceleration. Rate of onset has some threshold value and precedes the acceleration in



Equation for Sinusoidal Motion

$$d = \frac{g_m}{1.22\, f^2}$$

where: d = single-amplitude displacement in feet

g_m = maximum acceleration in g's

f = frequency in cps

NOTE: Displacement values represent absolute minimums. In motion simulation practice, a 10 to 20 percent safety factor is usually added.

Figure 33. Displacement Versus Frequency for Various Cyclic Accelerations (from Graham, 1968)

time. To put the simulator into motion, "requires that it be brought to a certain rate by an acceleration and to this acceleration by a certain rate of onset of acceleration, etc., each of these successive derivatives having occurred successively earlier in time... If the operator can sense this third derivative of position (jerk) proprioceptively and initiate even an approximate corrective response, he is considerably ahead of the visual sense alone in controlling the system." Less simulator displacement is required for the above-threshold value for rates of onset than is for accelerations.

Thus, the onset of the g force is presented, then the force is quickly faded away and the simulator returns to the neutral position without the man being aware of the washout of the force. Only a relatively small motion of the platform is required.

Wendt (1966) states that some laboratory studies yield "subliminal acceleration" ranging from about 0.3° to $0.5^{\circ}/\sec^2$. These are conservative (safe) and it is probable that washout levels in current simulators slightly less or of comparable orders of magnitude have been found acceptable. In practice, 0.1g washout accelerations for linear motion have also been employed in simulator design with some success.

The Link group (Flexman, et al, 1968) emphasize that the acceleration involved in washout should be subliminal, so as not to provide a false cue, but still remain as rapid as possible. Since for angular motion the product of latency time (time required to detect an acceleration) and the acceleration itself (the "Muelder product") is approximately constant for latencies less than 2.5 seconds (but cf. the qualifications stated earlier), the specification of fading acceleration is not a matter of setting a single acceleration limit. A higher fading acceleration can be tolerated when washing out a small angle than when washing out a large one, since the latter requires more time. Thus, while it would be safe to use an acceleration limit based upon a maximum excursion, this would result in needlessly slow returns from excursions less than the maximum. In addition, it is argued there that the thresholds obtained from laboratory data should be multiplied by a factor of 2 or 3 to account for the decreased sensitivity associated with task loading. The problem of washing out the velocity resulting from the acceleration while the trainee still continues to sense motion subjectively is crucial for design. A single cycle involves the following: onset of acceleration (jerk); the period of time taken by the velocity washout; and the time required to return the system to its zero position which involves both a subliminal acceleration and deceleration. This cycle is involved each time motion is generated.

The washout threshold has not received enough careful attention in simulator design. Wendt[1] says it has been ignored or left to incidental system characteristics whose parameters are not fully known. As a consequence, some commercial simulator users have found it practical to reduce motion system gain or even eliminate degrees of freedom along certain axes because of cue conflict or potential negative transfer incurred under such unfavorable circumstances which had not been anticipated.

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[1] Dr. Hans W. Wendt, personal communication.

Graham (1968) states that in practice, washout motions intrude considerably above the detection threshold and not much can be done about it, since humans are too sensitive to acceleration. The use of washout apparently incurs poor phase relationships among acceleration, velocity and displacement cues. Washout works best when the simulation as a whole is unrealistic. When the simulation is realistic, washout generates some confusion. The reason for this conjecture is that with unrealistic simulation, the man does not attend to all cues since he is aware that some are false, whereas in the realistic situation he attends to all cues and the erroneous washout cues make for confusion.

3.2.3.4.2 Scaling of Motion Forces. An option for design is partial force simulation involving a reduction in the dynamic range required of the motion platform. This calls for a scaling down of the cue forces from the correct amplitudes without affecting the functional relationships of the simulator in its operation. The obvious objection to this is that it degrades fidelity significantly. However, it may be argued that little functional difference would result since large inertial forces are not differentiated well (quantitatively) by man. In the visual motion context, these cues would tend to only inform him of the order or magnitude of the force until the visual cues become dominant. If this is true, then scaled down forces represent a functional similarity to actual motion forces provided they are: of the correct sense; inform the pilot of rough changes in magnitude; and do not incur cue conflicts. The latter point is important. Angular forces can be represented quite realistically at least more so than the translational forces. Now, if the key issue is conspicuous cue value, and if translations (surge, heave, etc.) usually occurred independently of rotation, then scaling would appear feasible. Under these circumstances a factor of up to 5 or even higher would be worth exploring. On the other hand, if the device to be simulated implies frequent compounding of linear and angular vectors, as in some maneuvers of high performance aircraft, then a combination of non-scaled angular forces with scaled linear ones may result in cue conflict and potential negative transfer. Intuitively it would seem that ranges can be found where satisfactory cue value and some positive transfer (or at least, absence of significant negative transfer) can be obtained from a scaling down of both translational and rotational accelerations even though simulator mechanics might permit higher and near-realistic formulas for certain rotational degrees of freedom. Unfortunately, the situation is further complicated by the observation that --aside from absolute thresholds--the differential thresholds for linear and angular motion appear to be quite different although research in this area has been rare. In practical terms, a 25 percent reduction in linear acceleration, for example, may be substantially different, subjectively, from a 25 percent reduction in a rotational component.

Graham (1968) states that scaling down has already been used successfully in the situation where pilots flew a representative aircraft prior to using the simulator. Using the Cooper Rating Scale for system evaluation, they were able to extrapolate the reduced acceleration cues. When a pilot experienced some difficulty in the simulator he could mentally multiply his problem and rate it accordingly. The use of objective performance measures (e.g., tracking error) could give erroneous results, however, in the scaled down situation.

3.2.3.4.3 Tilting of the Cockpit or Body. Tilting of the cockpit or the individual to resolve the normal gravity vector into a continuing subjective vertical vector and the equivalent of a longitudinal or lateral acceleration is another technique of some promise particularly when used in conjunction with customary motion systems. For example, pitch up of the cockpit can be used to provide a cue for forward acceleration; bank can be used to provide a cue for lateral motion (assuming a compatibility between visual and motion cues).

Wendt and Cohen[1] state that the tilt mode when added to the motion system for a commercial aircraft simulator has produced equivocal results. Pilots have reported conflicting and unrealistic sensations, even a feeling of sliding off the seat, etc. The writers believe, however, that one or more of the constraints inherent in the tilting technique have been violated, and in particular, there has been a failure to consider rotational acceleration thresholds. They list four conditions that must be met to assure the feasibility of the tilting technique:

a. Longitudinal or lateral G is above threshold to provide distinctive cue function.

b. The perceived G along the body vertical is indistinguishable from the normal 1 g level, to avoid the sensation of downward acceleration (falling).

c. The reduction of G along the body vertical is small enough to avoid the "sliding off the seat" effect in conjunction with the horizontal force component (the geometry of conditions a + b set the upper limit for any simulation of horizontal acceleration that can be achieved).

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[1] Wendt, H. W. and Cohen, E. *Simulating Lateral and Longitudinal Accelerations by Subliminal Tilting of the Operator Vertical*. Link Group Engineering Report, Binghamton, New York, 1969. (Pre-publication draft.)

d. The rotation of the body through pitch or bank occurs in such a way that the angular acceleration and deceleration of this auxiliary motion remains subliminal.

The tilting principle includes, unfortunately, incidental horizontal and vertical accelerations which interact with the buildup of the intended G state, but Wendt and Cohen calculate from available threshold data and the geometry of the human body, that their magnitude is not large enough to interfere with the intended simulation of longitudinal and lateral G. Generally, the feasibility of the tilting technique is determined by the angular acceleration thresholds of the man in the plane of tilting and by the extent to which loss of G along the vertical is subjectively perceived (with or without other side effects). The limiting angular motion thresholds are determined jointly by exposure duration and magnitude although their product is a constant only in gross approximation. Based on the available sensory threshold data and a number of realistic assumptions, the authors conclude that the absolute minimum delay is estimated at about 1.7 seconds longitudinal and 1.9 seconds lateral. In other words, a minimum of 1.7 seconds would be required from the beginning of the tilting to first sense a forward acceleration (at or slightly above threshold) and yet not sense the rotation which is a necessary part of this simulation technique. For a simulated level of 0.2 g longitudinal, transition to the endpoint requires from 4 to 9 seconds (depending on details of the tilting program used). The upper feasible limit for simulation seems to be between 0.3 g and 0.4 g, and indirectly determined by distortions of the vertical G vector. For 0.4 g, the minimum theoretical delay is calculated as 7.8 seconds for the longitudinal acceleration mode simulated by pitch angle. So far as the maximum rate of change of G that can be simulated is concerned, similar calculations lead to an order of 0.05 g/second.

It appears that the tilting technique should provide adequate fidelity when combined with a two or a three degree of freedom motion platform. The tilting would simulate--in some instances fully so--the required sustained and more stable G components; the conventional platform would reproduce higher frequency vertical and longitudinal or lateral motion. Wendt and Cohen state that the tilting principle is not applicable in vehicle simulation when normal maneuvers involve absolute G loads in excess of 0.5 to 0.6, or for loads whose final sustained magnitude is reached at rates in excess of 0.4 to 0.5 g/second.

3.2.3.4.4 Differential Pressures on the Body as Motion Cues. Some exploratory work has been devoted to producing motion cues by stimulating portions of the body. These include controlled pressure redistributions by means of inflatable seats and backrests, by altering tensions on seat belts/shoulder harnesses, and by means of duplicating the shearing forces at the major support points of the human which accompany actual accelerations.

Inflatable seat cushions and seat belt/shoulder harness tension devices (for vertical or longitudinal G) serve to signal the pilot that accelerations are occurring. As such they may serve most usefully when supplemented by brief physical motion cues supported by relevant visual cues. To simulate sustained longitudinal acceleration (e.g., takeoff roll), the sequence could be as follows: the acceleration onset (jerk), which is then washed out, coupled with pressures on the harness or against the pilot's back plus the visual cues of increasing speed along the runway (and tilting of the pilot vertical).

A pneumatic seat system made up of six differentially inflatable sections was developed for providing subjectively valid motion cues while not moving the cockpit (Barrett, et al, 1969). The seat, via computer controlled air pressure, produced buffeting effects, small displacements (0-20 Hz range), acceleration, long term coordinated and uncoordinated turns, pullouts and pushovers and deceleration effects simulating a landing approach. It also simulated turbulence and general background vibration. The seat motion significantly increased realism for a series of six maneuvers flown by eight general aviation pilots. When the pilots, blindfolded, were presented the motion cues, they identified correctly the maneuvers at an 85% average.

Powe, et al (1963), employing a segmented air cushion for producing differential pressure effects reported that the seat magnified the amount of tilt by a factor of 2.5. The Link group, General Precision Systems, has also developed a technique for partially simulating acceleration cues with the design of a harness system involving tension adjustments.

These exploratory studies exemplify the attempt to induce the perception of motion by pressures on the human body instead of moving the aircraft cockpit. The economies of this approach for training, however, have not been verified nor are sufficient data available for comparisons with other techniques, or to justify the approach as a means of augmenting physical motion in the simulator except on theoretical and rational grounds.

3.2.3.4.5 Shearing Forces. One study[1] investigated the sensations resulting from major shearing forces arising at the man/support interfaces. The forces of concern are described below. Figure 34 depicts the pressure points for a linear accelerating vehicle; Figure 35 depicts the pressure points when the vehicle makes a large radius turn to the right (lateral acceleration). In this study, 12 blindfolded females were

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[1] Wendt, H.W., Farley, W.R., Bergwall, D.W. and Bucher, B.G. Acceleration feel as a function of acceleration. Unpublished study. Valparaiso University, Department of Psychology, May, 1968.

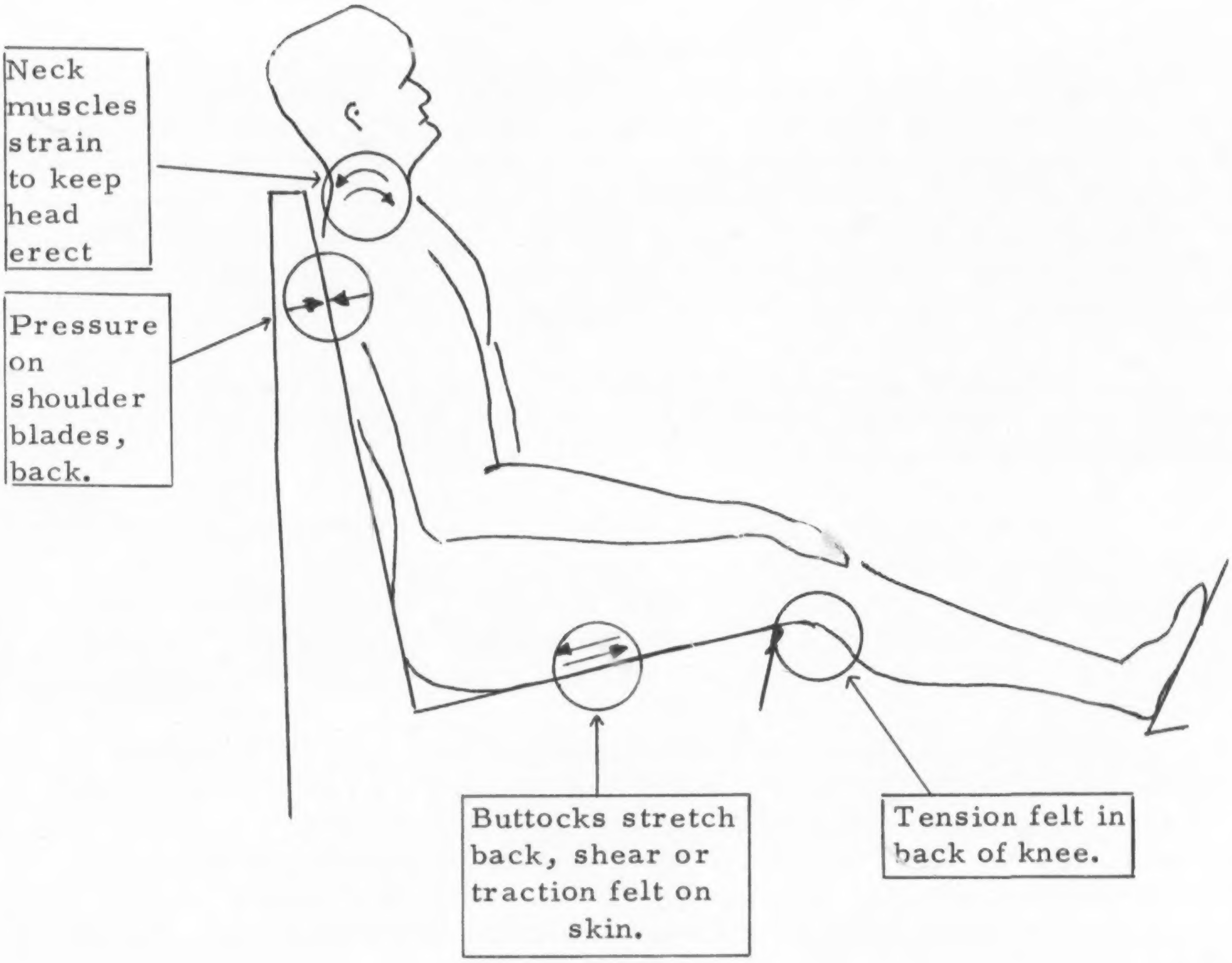
Neck muscles strain to keep head erect
Pressure on shoulder blades, back.
Buttocks stretch back, shear or traction felt on skin.
Tension felt in back of knee.

Figure 34. Sensations in Vehicle Linear Acceleration.

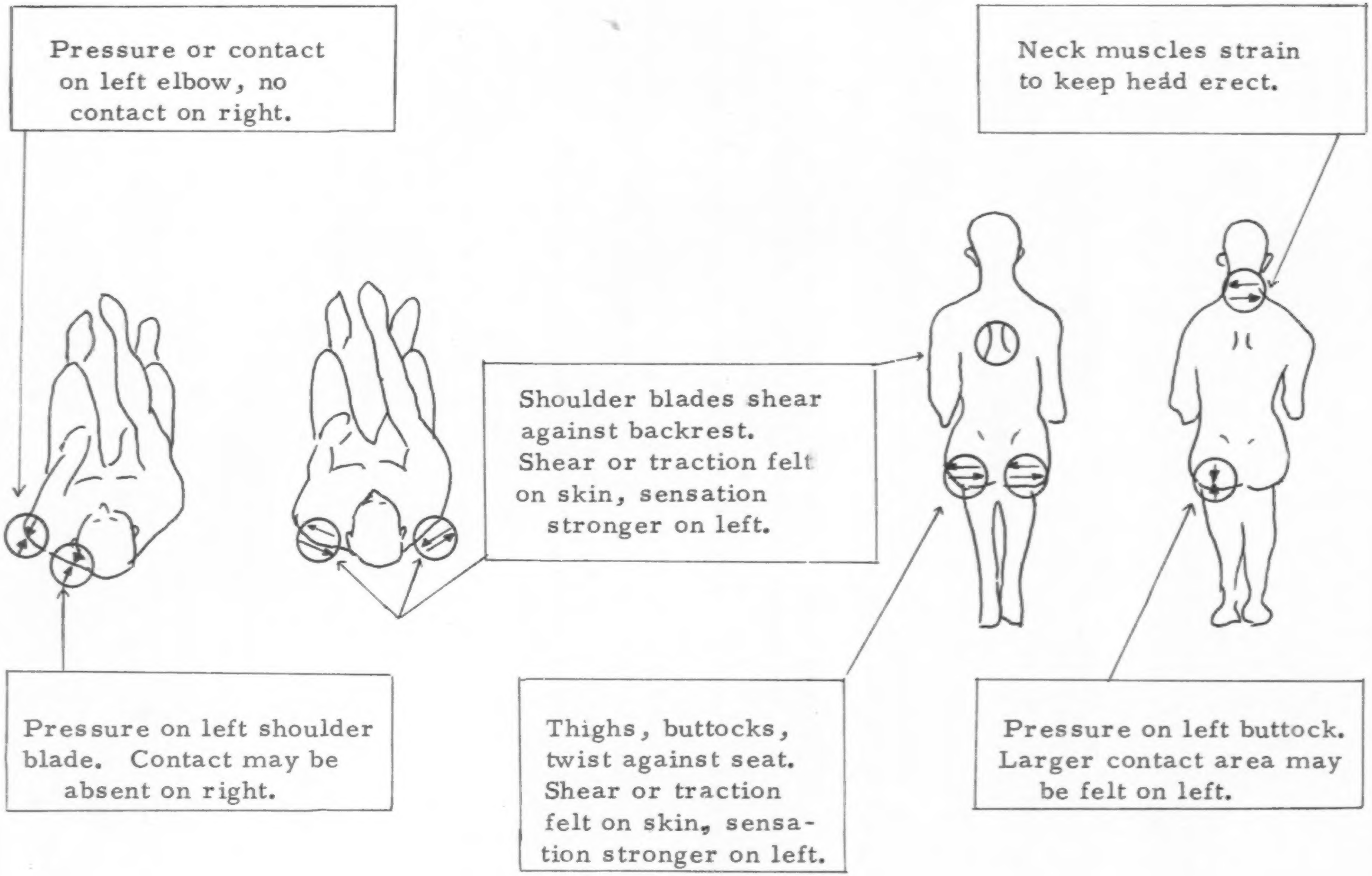
Pressure or contact on left elbow, no contact on right.
Neck muscles strain to keep head erect.
Shoulder blades shear against backrest. Shear or traction felt on skin, sensation stronger on left.
Pressure on left shoulder blade. Contact may be absent on right.
Thighs, buttocks, twist against seat. Shear or traction felt on skin, sensation stronger on left.
Pressure on left buttock. Larger contact area may be felt on left.

Figure 35. Sensations for a Large Radius Turn to the Right (or Lateral Accelerations)

subjected to acceleration, deceleration and lateral acceleration in the realistic environment of a moving automobile. Acceleration was held to 0.15 g under all conditions, and the median duration of exposure was 7 seconds. The subjects were instructed to observe closely their sensations and to indicate their order of appearance as well as relative prominence. The purpose was to study the role that normal pressure as well as shear forces would play in the subjective experience so that, in later systematic attempts (and hopefully, using a more versatile motion platform) the "natural" cues available to an operator undergoing acceleration could be synthesized. For example, a shear force normally apparent, and often conspicuous, in the shoulder region during lateral acceleration can be duplicated by keeping the operator torso stationary while sliding a movable portion of the backrest against his shoulder blades. The chief results were as follows:

a. Generally, sensations are substantially more prominent in the upper half of the body than below the waistline.

b. The rank orders obtained for "appearance" and "prominence" are essentially the same. To the extent that differences should be found in subsequent studies, it is believed that for purposes of simulation, the ordering in time should be given more consideration than "prominence."

c. The rank orders differ somewhat for the three conditions. This is taken to indicate that simulation can capitalize on different patterns as well as on the appearance or non-appearance of a given cue type. The following rank orders were obtained for the three most conspicuous areas for each experimental condition:

Forward acceleration	Neck/head	This cue almost uniformly emerges as the first one noticed by all subjects; it appears to be substantially more important than the other two.
	Shoulder/back	
	Buttocks	
Forward deceleration (braking, etc.)	Shoulder/back	
	Neck/head	

Forward deceleration (braking, etc.) (continued)	Hands, feet	In terms of inter-subject variability the order here is less clearcut than in either forward or lateral acceleration.
Lateral acceleration (wide circle turn or other)	Shoulder/back	This cue region appears to be much more important than the ones following.
	Thighs	
	Elbows	

3.2.4 Some Specifications for Achieving Motion. It is obvious that general prescriptions for incorporating motion into the design of ground-based trainers do not exist. There is no "standard" set of data for the design of motion systems for simulators and the data available are not sufficient as a body of knowledge to serve as guidelines on the kinds and amount of motion displacement required for simulating motion cues. The lack of standard guidelines to design is compounded by the feature that motion systems must be "tailored" to the training tasks specified for the simulator and to the characteristics of the aircraft involved, since motion cues are dependent on the aircraft type being simulated. Task analysis is required (see Section II of this report) in order to specify those motion parameters and values most suited to the training purpose of the device. Thus, design practices today rely more on empirical solutions rather than on precise quantitative information; definitions of motion requirements tend to be subjective based primarily upon operating practices (including best estimates, combinations of research data and logic, and "on-site" tryouts conducted by professionals from the user agency).

The specifications for the simulated motion system is based on the design characteristics of the given aircraft type. The current practice is mirrored in the Military Specifications (MIL-T 8235) and MIL-T 9212B (USAF) for Flight Trainers. The general motion requirements for simulators are exerpted below. An example of a specific motion system requirement (for Device 2B24 Synthetic Flight Training System[1]) is also excerpted.

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[1] Specification for Synthetic Flight Training System, Engineering Development Model Device 2B24, 353-514 Task, 1955, U.S. Naval Training Device Center, Orlando, Florida, 13 September1968.

MIL T 8235:

- Motion simulation. When specified in the detail trainer specification, the cockpit shall be capable of limited motion to produce kinesthetic sensations representative of those experienced in the design basis aircraft in the areas specified herein. The following limits of motion from the neutral altitude shall apply:

(a) Angular rotation in roll	plus or minus 15 degrees
(b) Angular rotation in pitch	plus or minus 15 degrees
(c) Vertical translation at the pilot position	plus or minus 6 inches

  - Motion resulting from flight maneuvers. Within the available limits of motion, the cockpit shall respond to flight control inputs by motion, in the appropriate angular or translational sense, so as to simulate the onset of acceleration forces associated with the resulting maneuver up to an increment of at least 0.5g force. Following the initial transient g force, (a) for maneuvers which result in unaccelerated flight, the cockpit attitude shall correspond to the flight attitude, and (b) for maneuvers which result in positive accelerated flight, the cockpit shall return slowly and imperceptibly to normal straight and level flight attitude. The aircraft instrument indications shall reflect the actual simulated flight condition regardless of cockpit attitude.

  - Oscillations and vibrations. Characteristic periodic oscillations and vibrations shall be qualitatively simulated by the application of frequencies, amplitudes, and directions representative of those in the design basis aircraft.

  - Background motion. A random, low-frequency, low-amplitude, multidirectional cockpit oscillation with repetition cycles of not less than 15 minutes duration shall be provided to simulate the effect of being in other than a stationary platform. Such simulation shall be controllable in intensity so as to simulate varying degrees of rough air. Instrument indications shall be qualitatively affected by rough air.

  - Motion system operation and control. The motion system shall operate smoothly without hunting or snubbing against fixed stops, in such a manner as not to cause damage to equipment or injury or unrealistic discomfort to trainees or other personnel. Overall system energization and activation and each mode of operation shall be separately controllable by the instructor with appropriate indication of the mode of operation and power energization. Energization or activation shall not be possible without positive arming action by and indication to the trainee seated in the cockpit. It shall also be possible for the trainee, by easily accessible control, to completely deactivate the system at any time. Initial system activation and energization as well as deactivation or deenergization by whatever means accomplished shall be smooth and gradual with no sudden or abrupt motion imparted to any part of the system structure. Whenever the system is or becomes deactivated, it shall remain or return to a neutral level position. When it is completely deenergized, it shall be seated in the neutral, level position on a suitable supporting cradle or framework so that all actuating elements are unloaded and operation of the motion system is prevented. In case of any motion of the cockpit beyond its normal operating limits, or of any failure or malfunction, in the motion actuating system itself or in any other trainer system that might result in the introduction of spurious signals into the actuators, the motion system shall automatically deactivate. When such failure involves loss of the motion system power source, return to a neutral position shall not be required.

MIL-T-9212B (USAF):

Motion system limits. Unless otherwise specified in the detail specification, the motion system shall allow movement in six degrees of freedom. Movement in each degree of freedom shall be capable of occurring independently without simultaneous motion in any other degree of freedom. The motion and limits of movement in any degree of freedom shall not be restricted by the positioning of the trainer; for example, it shall be possible for maximum pitchup to occur when the trainer compartment is positioned at the upper limits of vertical translation. Also, roll limits and performance shall be unaffected by trainer compartment position. It is emphasized that the limits of this paragraph represent performance criteria and not actual design limits. With respect to the trainer flight compartment axes, the displacement limits of motion shall be in accordance with the following guidelines:

Vertical translation--The vertical displacement of the trainer flight compartment shall be:

$$Y_m = \frac{3.5}{\omega^2}$$

where

Y_m = Total vertical displacement in inches.

ω = Most predominant frequency felt by the aircraft crew at the design velocity, altitude, and configuration under a 1 cps rms vertical gust environment, in cycles per second.

Unless otherwise specified in the detail specification, the vertical displacement shall be:

0 - 24 inches minimum
0 - 30 inches maximum.

Lateral translation--The lateral translation shall be as determined by acceleration requirements.

Longitudinal translation--The longitudinal translation shall be as determined by acceleration requirements.

Roll displacement--The roll displacement shall be determined as a function of the maximum roll acceleration experienced in the aircraft. The minimum displacement limits shall be:

$\pm 15^\circ$ for high performance aircraft.
$\pm 9^\circ$ for medium performance aircraft.

(NOTE: The distinction between high performance and low performance aircraft will be made by the procuring activity.)

Pitch displacement--The pitch displacement shall be:

For high performance aircraft: $+14^\circ$
-9°

For medium performance aircraft:

$+(\alpha_{ST} + 1^\circ)$ or 14°, whichever is smaller

-9° where α_{ST} = angle of attack for aircraft stall

Yaw displacement--Unless otherwise specified in the detail specification, yaw displacement shall not ordinarily be simulated. It shall be considered carefully for VSTOL aircraft and a rationale for its inclusion or exclusion submitted to the procuring activity.

Motion system accelerations. The motion system accelerations shall not adversely affect the performance or durability of any other component of the trainer, including instruments and instrument indications. The maximum accelerations shall be determined as follows:

Vertical acceleration--Vertical acceleration shall be ±0.8g above or below normal 1g.

Lateral acceleration--Lateral acceleration requirements shall be determined by the lateral acceleration experienced in the aircraft under a 2 feet per second rms gust condition, or as specified in the detail specification.

Longitudinal acceleration--The requirements for longitudinal acceleration shall be determined from the accelerations experienced in the aircraft when thrust minus drag (T - D) is a maximum, or as delineated in the detail specification.

Roll acceleration--The maximum roll acceleration provided shall be consistent with operational performance. Unless otherwise specified, the lowest acceptable value for maximum acceleration shall be ±50° per second^2.

Pitch acceleration--The pitch acceleration shall be as determined from the aircraft pitch acceleration, consistent with operational performance. Unless otherwise specified in the detailed specification, the minimum value for maximum pitch acceleration shall be ±25° per second^2.

Yaw acceleration--Yaw acceleration shall be in accordance with the detail specification.

The acceleration provided in all degrees of freedom shall be realistically coordinated. The exact degree of motion simulation to be provided shall be compared to comparable aircraft motions and presented to the procuring activity for approval.

Device 2B24:

Motion system limits. The motion system shall allow movement in four degrees of freedom. Movement in each degree of freedom shall be capable of occurring independently without simultaneous motion in any other degree of freedom. The motion and limits of movement in any degree of freedom shall not be restricted by the positioning of the trainer; for example, it shall be possible for maximum pitchup to occur when the trainee station is positioned at the upper limits of vertical translation. Also, roll limits and performance shall not be affected by trainee station position. It is emphasized that the limits of this paragraph represent performance criteria and not actual design limits. With respect to the trainee station axes, the displacement limits of motion shall be in accordance with the following guidelines:

(a) Vertical displacement--The vertical displacement of the trainee station shall be:

0 - 24 inches minimum
0 - 30 inches maximum

(b) Roll displacement--The roll displacement shall be determined as a function of the maximum roll acceleration experienced in the aircraft. The minimum displacement limits shall be: ±15°

(c) Pitch displacement--The minimum pitch displacement shall be: +15°

(d) Yaw displacement--The minimum yaw displacement shall be: +15°

Degree of simulation. With respect to the trainee station axes, the physical movement of the trainee station shall be along and about the Z-axis (vertical and yaw), about the Y-axis (pitch), and about the X-axis (roll). The sensations of motion shall be representative of sensations experienced in the operational aircraft resulting from changes in attitude and/or the flight path. Representative motion caused by the following aircraft conditions shall be provided: Buffets, blade stall, skids, slips, banks, turns, hovering climbs, dives, rolls, acceleration and deceleration, release of stores, vibrations, oscillations, touchdown attitude and impact, and control-induced changes in the exterior configuration of the aircraft.

Motion system computations. The physical motion system movement shall be determined by computations based upon six degrees of aircraft freedom. Movement along or about all axes of the motion system shall be correctly correlated with the motion of the simulated aircraft. All aircraft stability derivatives shall be accounted for in such a manner that aircraft movement in any degree of freedom shall correctly influence movement along or about every axis of the motion system. The motion system shall respond correctly to aircraft center of gravity or center of pressure movements, including: fuel depletion, cargo drops, pod drops, loss of tail rotor and/or loss of tail rotor gear box, and aerodynamic effects. The acceleration of the trainee station in any degree of freedom shall not exceed the aircraft acceleration experienced under similar flight and configuration conditions of the operational aircraft simulated.

Operational performance. The motion system design shall emphasize onset of accelerations to provide correct physical sensations of motion to the trainee. Following the initial transient force, the cockpit shall return slowly and imperceptibly to normal straight and level flight attitude, except that the cockpit shall maintain an appropriate amount of the commanded pitch attitude. The aircraft instrument indications shall reflect the actual simulated flight condition regardless of cockpit attitude. There shall be no noticeable time error between instrument response and trainee station movement except as appropriate to a given instrument such as rate of climb.

Motion system accelerations. The motion system accelerations shall not adversely affect the performance or durability of any other component of the trainer, including instruments and instrument indications. The maximum accelerations shall be determined as follows:

(a) Vertical acceleration--The lowest acceptable value for maximum vertical acceleration shall be 0.5g above and below the normal 1g

(b) Roll acceleration--The lowest acceptable value for maximum roll acceleration shall be $\pm 70^\circ$ per second^2

(c) Pitch acceleration--The lowest acceptable value for maximum pitch acceleration shall be $\pm 25^\circ$ per second^2

(d) Yaw acceleration--The lowest acceptable value for maximum yaw acceleration shall be $\pm 100^\circ$ per second^2

The acceleration provided in all degrees of freedom shall be realistically coordinated. The exact degree of motion simulation to be provided shall be compared to comparable aircraft motions.

Smoothness. The motion system shall not operate erratically. The system shall operate smoothly without hunting and shall not snub against cushion stops during normal operation. The actuator system shall smoothly raise the trainer in a reasonable level attitude to the initial operational position. Oscillations of the trainee station caused by motion system instability shall not occur. Oscillations of the trainee station or any of its components as a result of structural, hydraulic, or electrical resonance shall not occur, unless such movement is demanded by the equations of motion of the flight aircraft.

Oscillations and vibrations. Characteristic continuous and periodic oscillations and vibrations shall be qualitatively simulated by the applications of frequencies, amplitudes and directions representative of those experienced in normal and emergency flight conditions and maneuvers. (End of exerpt from device 2B24, motion system requirements.)

Some design practices found to be useful by various simulator groups as well as selected information and data pertinent as guidelines for design are set forth here.

The Link proposal for the Synthetic Flight Training System, Device 2B24, (Flexman, et al, 1968) states that pitch, roll and heave, as well as yaw (if costs can be justified) motions should be incorporated into any helicopter trainer motion platform. To provide the yaw cue, yaw motion can be resolved into an angular component (rotation around a vertical axis through the pilot's spinal column) and translational components (lateral motion plus a negligible amount of longitudinal motion), since the pilot is about 6 feet forward of the center of gravity for the UH-1D helicopter. Link accepts research data that indicate a detection of yaw acceleration at about $1^{\circ}/\text{sec}^2$ with a latency of 2 seconds. The lateral acceleration detectable with the same 2 second latency is approximately 0.02g, or 0.6 ft/sec^2. Since each $1^{\circ}/\text{sec}^2$ acceleration about a yaw axis six feet away produces a lateral acceleration of about 0.1 ft/sec^2, it appears that the rotary component will reach threshold before the lateral component does, and hence it could be inferred that rotation is a more significant cue for yaw than is lateral translation. Similar results follow the examination of thresholds at other latencies; at 1/2 second, for example, their values are $10^{\circ}/\text{sec}^2$ for angular threshold, 0.3g for lateral acceleration threshold, and a threshold ratio, at the 6 ft. distance, of 1:10, rather than the 1:6 obtained at 2 seconds. Thus, a sufficient yaw cue can be provided by rotation alone around a vertical axis near the pilot's spinal column, without providing the lateral translation that occurs in the aircraft when it yaws. (Note, this does not hold for the CH-47A helicopter since the center of gravity is 19.5 feet behind the pilot and the threshold ratios for the aircraft are on the order of 1:2 to 1:3. Hence, the desirability of lateral motion for the CH-47A cannot be ruled out.) With respect to vertical motion (heave), the same design philosophy is employed: provide a vertical travel ample to allow an onset cue well above laboratory threshold, and a fading to the neutral position with subliminal acceleration. A straightforward derivation of requirements from laboratory thresholds is not possible, due to the absence of data separating the effects of acceleration from that of jerk (the first derivation of acceleration with respect to time). Experience has shown that a 24-inch vertical motion (±12"), with a velocity limit of 18"/sec, and an acceleration capability of 1 ± 0.8g, is satisfactory. This may exceed training requirements. A vibration capability is also provided to represent environmental effects and the specific cues present in the aircraft.

Past experience with simulation fidelity has shown that motion systems demonstrating ±12 inches of translational motion and ±10 degrees of angular motion have fulfilled many needs for pilot training simulation (Clausen, et al, 1968).

A number of useful guidelines for programing the motion system has been forwarded by Borlace (1967). Among these are the following:

- The acceleration used should be that of the cockpit and not that of the center of gravity, and should account for aircraft flexure.
- Low speed responses will be required by the motion system so that these may be washed out by accelerations below the threshold for the vestibular system, since granularity or irregularity is immediately apparent to the pilot. This necessitates a wide dynamic range of the motion system.
- Pitching the cockpit to generate the effect of longitudinal acceleration, while it gives good simulation at the achieved angle, yields false sensations during the angular motions (when the semi-circular canal signals swamp those of the otiliths and give wrong sensations). The same applies to rolling the cockpit to generate sway or side force. (however, see the Wendt and Cohen (1969) calculation cited earlier).
- The combination of pitch and simultaneous heave is unusually effective because the linear acceleration output of the otoliths is the component of this acceleration resolved along its plane (not the vertical). Pitching increases this component and so pitch accentuates the corresponding heave motion when they are applied together.

Apparently, there are real limitations to the number of degrees of freedom that can provide realistic motions at one time. These will vary with the particular aircraft and displacements required. For conventional aircraft, pitch, roll and normal acceleration should be adequate to meet most requirements. For V/STOL aircraft, yaw should be included. When aircraft cockpits are far removed from the center of gravity, side acceleration should be included possibly in place of yaw. With five degree of motion simulation, it becomes more difficult to keep the simulator free of unwanted motions because of the finite restrictions imposed by the allowable displacements. Centrifugal acceleration is imposed by rotation and the gimbal adjustments necessary to maintain proper cockpit acceleration and alignment.[1]

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[1] Communication with John Conant, Melpar Corporation, Falls Church, Virginia.

Boeing (Graham, 1968) has specified a simulator (for crew station research and development) where pitch, roll and heave are the important axes. Sway, followed by yaw are important when the pilot is displaced some distance from the center of gravity, since yaw is sensed as a sway condition. Yaw becomes increasingly dominant over sway when the cockpit is close to the center of gravity. Surge is only critical for the simulation of buffet or high-level, long-term longitudinal acceleration. Table 22 presents specifications for a six-degree of freedom moving base simulator. The simulator drive should be able to produce vertical vibration frequencies from 0.1 to 20.0 cps at amplitudes sufficient to attain an rms level of 0.5g (at frequencies above 1.5 cps). Lateral frequencies from 0.5 to 10.0 cps appear necessary. (The lateral rms "g" vibration level is currently undetermined.) Thus, any flight simulator having a research emphasis should possess at least four degrees of freedom; specifically pitch, roll, heave and sway, and be constructed such that the remaining two degrees can be added without major redesign.

The pivot point of the motion platform relative to the location of the pilot is important in cue presentation. The simulated pivot point should approximate the actual pivot point of the aircraft. In large aircraft where the cockpit is well ahead of the yaw pivot point, yaw is sensed as sway. When the pilot is located near the pivot point, pitching motion is experienced as angular acceleration much more so than as vertical motion; where the cockpit is located near the yaw pivot point, the rotational element of yaw is easily perceived.

Pilots are required not only to detect movement but also to identify the plane of the movement, hence the perception of motion for combined axes is of some importance with multi-degree of freedom simulators. Very little useful data for design exist on this issue. Spatial disorientation in flight can occur by an acceleration vector mistaken for the gravitational vertical. Head movements about an axis other than the axis of rotation (coriolis effect) can modify sensations of turning (see Stewart and Clark, 1965). Graham (1968) cites the assumption that the vestibular sensory system can be used to create the illusion of movement, but how to exploit this possibility for design is poorly understood. In addition to possible vestibular cross-coupling effects, interactions presumably take place between the vestibular and somesthetic senses. Further, spatial orientation is normally achieved visually and visual cues are dominant over somesthetic cues in the competition for man's attention. This, of course, provides the rationale for giving the illusion of sustained cockpit motion by continuously driving the horizon in the aircraft attitude indicator following only a transient movement of the cockpit itself.

3.2.4.1 Visual Motion Interactions. The use of visual cues to augment motion cues is of considerable interest to design since visual motion complements motion sensed proprioceptively. Combining elementary or

TABLE 22. SIMULATOR MOTION SPECIFICATIONS

Axis	Displacement	Acceleration*	R&D Use Application
Vertical	±25 ft. Minimum Required ±85 ft. Desired	± 8g @ 1.0 cps	Turbulence, PIO, and Terrain Following
Lateral	±10 ft.	32 ft/sec^2	"Abnormal" landing conditions, turbulence, and V/STOL operations
Longitudinal	±10 ft.	32 ft/sec^2	
Pitch	±45°	340 deg/sec^2	All of the above
Roll	±60°	680 deg/sec^2	
Yaw	±45°	400 deg/sec^2	

*"g" levels are referenced to normal gravity as the zero condition. Hence, +1 vertical "g" doubles the aircrew's weight, while -1 vertical "g" renders them weightless.

(from Graham, 1968.)

minimal motion such as a random heaving motion with a high fidelity visual velocity cue, has given rise to subjective reports from pilots that they are in a moving vehicle. This involves signalling the pilot of the onset of an acceleration followed by motion washout but continuing with the high fidelity visual cue.

The predictive value of an acceleration cue in a visual-motion cue environment is well understood. Most often, an acceleration cue leads the visual velocity cue in time of perception. Matheny, Dougherty and Willis (1963) indicate that in systems which are accelerated at about $7^o/sec^2$, the visual and motion stimuli are responded to at the same time. However, when the acceleration reaches about $20^o/sec^2$ the motion cues precede the visual cues significantly. At an angular acceleration of about $25^o/sec^2$, motion cues precede the visual cues by .4 to .5 seconds.

Providing extra-cockpit visual cues for augmenting motion is highly valued. Visual motion can effectively mask contradicting physical motion cues resulting from washout. However, it is the interaction between visual and motion cues that make simulation for training exceptionally difficult. When visual and motion cues are used interactively, both must be realistic in quality and temporal relations. This is much easier said than done.

Motion may be induced visually in the absence of physical motion, but the use of vivid extra-cockpit motion cues (visually induced motion via a projection of sky and terrain onto a screen) in the absence of physical motion has limited value. The absence of physical motion denies the pilot the predictive value of acceleration cues and he must rely on sensing the visual velocity (which is different from that of the flight environment). Also, visual attitude cues conflict with vestibular cues giving rise to undesirable side effects in the simulator such as nausea and vertigo. Studies utilizing multiple cues (visual and proprioceptive) in helicopter simulation suggest that nausea and vertigo result from distorted optical motion rather than from a conflict of the visual and proprioceptive cues (Miller & Goodson, 1958; Sinacori, 1969).

3.2.4.2 Vibration. Vibration is also an issue of some concern to simulation. It is an important design feature in that the pilot uses vibration, buzzing, buffeting, etc., as a cue for how the aircraft is handling. Also, certain vibrations of the aircraft causes the pilot's head and eyes to vibrate, hence, have an effect on visual acuity and psychomotor performance. Our interest in vibration centers on its implications for the design of flight simulators in terms of decisions on incorporating vibration into the device and on what parameter values to specify. It is not our purpose to provide a review of the data on vibration effects on human performance. A considerable body of literature exists concerning: the physiological effects of vibration on the human body; the effects of vibration on human performance relative to visual, psychomotor and cognitive performance; and the conditions arising from vibration exposure, such as motion sickness and fatigue. A number of review studies have been published detailing these effects, and the reader is urged to consult these. Noteworthy among the reports are the surveys by Goldman and Von Gierke (1960), Harris and Crede (1961), Hornick (1961), Human Factors Journal (October 1962), Townsend (1967), and Roth (1968). Also, a survey of data on comfort limitations in high speed ground transports has been published by Carstens and Kresge (1965).

The primary vibration spectrum for aircraft that is most critical for the seated pilot falls within the frequency range of about one-half to twenty cycles per second. Frequencies lower than this do not have a direct effect on performance but may induce nausea; feequencies above 20 cycles per second can be effectively isolated from the pilot. It has been determined, for example, (Graham, 1968), that short-period mode pitch and yaw frequency response for four engine jets is in the range of 0.25 to 1.0 cps; bending mode response produces vibration in the range of 1 to 6 cps; vibrations above 6 cps are, in general, produced by turbulence. Since we are interested in the effects of vibration on performance, the level of acceleration is normally less than one. Within the 1 to 20 cps range, Hornick (1962) suggests that the following kinds of activities are affected in certain frequency ranges:

Axis	Frequency*	Effects
Vertical	1-6 cps	Choice reaction time
	5-15 cps	Tracking
	above 10 cps	Visual acuity
	below 7.5 cps	Speech intelligibility
	11 cps	Breathing
Transverse and Longitudinal	1-6 cps	Choice reaction time
	1.5 cps	Tracking
	1.5-5.5 cps	Breathing

---

*Values given are frequencies or frequency ranges where effect is most pronounced.

The perceptibility of vibration (sinusoidal) depends upon frequency and amplitude. In general, as frequency increases, amplitude can decrease to provide the same level of perceptibility. However, for the threshold defined as "definitely perceptible," the function is complex. The fluctuations in amplitude as frequency increases to produce the sensation of definitely perceptible vibration have been determined by Parks (1962) as follows:

Frequency (cps)	Double amplitude (inches)
1	.27
2	.17
5	.025
10	.030
15	.035
20	.016
25	.005

The conclusion drawn from many studies is that neither frequency nor intensity of vibration alone determines discomfort or performance degradation. Neglecting body resonance points for the moment, discomfort will increase as frequency increases with amplitude held constant; increasing the amplitude at a higher frequency increases discomfort more so than increasing the amplitude at a lower frequency. The following parameters must be considered in meaningful specifications of vibration:

- kind of vibration (sine, random, pre-recorded or programed)
- frequency (cycles per second)
- displacement (amplitude) (inches or millimeters of double amplitude)
- velocity (inches/sec, millimeters/sec)
- acceleration (ft/sec^2)
- jerk (inches/sec^3)

Anecdotal evidence indicates that vibration cues distinctly improve the realism in the control of the simulator. Vibration is especially important in helicopter simulation. Various reports of helicopter accidents due to confusion and spatial disorientation are attributable to a mix of degraded visibility conditions, coriolis effects, vibration, noise and oscillation from the vehicle's inherent instability. The vibration is not simply vertical or horizontal, but contains motion components in every direction. Additionally, the interaction of the rotor blades with portions of the fuselage causes vibration containing many frequency components. Magnitude of acceleration and amplitude vary similarly. Helicopter vibration lies predominantly in the spectrum of 10-70 cps with amplitudes ranging from 0.4 mm for 70 cps to 2.4 mm for 10 cps (Hornick, 1961). Because of the high amplitudes involved for low frequencies, concern should be shown for vibrations below 20 cps.

Matheny and Wilkerson (1966) cite the work of Kretz with the Giravions Dorand light helicopter simulator for training French pilots. Vibratory motion uncorrelated with changes in visual displays produced significant savings in flight training time. The effect produced is that of breaking the simulator loose from the ground and thus increasing the realism of the training situation. Although not tested experimentally, motion simulation of this vibrating type may enhance transfer of training at a relatively low cost.

In the development of an air-to-air combat simulator[1] the full vibration spectrum of the aircraft is deemed essential in simulation. Pilots rely on the feel of vibration to judge how close they are flying to the limits of the aircraft capability. Fighter aircraft become uncontrollable at the limits of capability rather than at the point of structural failure. Since the pilot cannot with surety rely on his instruments while attending to a foe to determine how close he is to the limits, he must rely on feel and sound to determine safety range. Thus, simulation must accurately represent the sound and vibration spectrum throughout all speeds, attitudes and altitudes of the aircraft. Simulation accuracy is particularly important in the region where aircraft control is lost. Emphasis must also be placed on isolating the vibration from the visual display system so as not to impair visual acuity except as the man's head vibrates. Therefore, vibration is best limited to the seat and to the controls normally used during combat maneuvers. Clousing (1964) has reported improved realism of the minimum unstick speed maneuver on a fixed simulator by vibrating a pneumatic seat cushion and installing a control column shaker.

The vibration tolerance curve for military aircraft has been established at 0.1 g (at the man) between 1 and 20 cps (Goldman, 1961); Wolbers (1959) has suggested a limit of 0.00015 inches double amplitude at frequencies below 60 cps. No consistent limit has been specified for exposure to low frequency vibration.

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[1] Communication with John Conant, Melpar Corporation, Falls Church, Virginia.

Graham (1968) states that vibration reproduction poses no serious design problems but reproduction of large displacements below 1 cps is a design problem having no simple solution.

3.2.5 Research Issues. A system of precise quantitative information is not available as a design guide for motion simulation. No organized set of "standards" are available that provide guidance on the design of motion systems for training simulators. To be sure, there exists a body of knowledge relevant to simulator design (and this information continues to grow) but it falls considerably short of the data requirements for human factors design. The reasons for this and the shortcomings in the information base have already been discussed. Because of this state of affairs, whatever success motion systems have enjoyed in flight trainers has resulted more from an empirical approach to design rather than from well documented design principles and data.

We are proposing here a number of human factors design issues that may be examined profitably to enhance the information base on which design decisions are predicated. These research issues are outlined below. They are not ranked in any order of primacy nor do they suggest similar levels of effort.

a. An information base on sensory thresholds for acceleration forces within the envelopes pertinent to training device design is needed. The emphasis here is on task situations and motion parameters relevant to current sophisticated flight simulators and other complex vehicle types. The basic laboratory data on sensory thresholds that have been assembled during this century are not directly applicable to simulator design requirements primarily because of the relatively simple task situations investigated, the non-comparability among studies (as to latency times, task differences) and the concentration on single axes of motion. Also, laboratory studies characteristically require the subject to attend to a single task requirement (unlike the much higher operational task loadings) in which he is alerted to the most minimal changes in motion cues. At best, laboratory data indicate what the man cannot perceive or utilize operationally. Thus, the effective thresholds for design will be raised considerably. What the pertinent relationships are should be determined systematically.

b. Allied to (a) above, is the need for a data base on the perception of motion (thresholds and definition, direction and quality of the experience) for combined axes. Of concern are the multi-axis interactions associated with current sophisticated flight simulators. It is well understood that the effective axis of acceleration in the operational environment seldom falls on any one orthogonal axis but is a vector with components of each.

c. In view of the difficulties in achieving full representation of physical motion in the simulator, a crucial research issue concerns an examination of cue values in less than the complete motion axes simulation. Since representing 6 degrees of freedom cannot be achieved except for brief time durations, the question of importance is what can be dropped out without seriously compromising the training capability? This is to say, how little motion can you get away with vis-a-vis specific task requirements? The issue revolves around the priority of motion axes and how many parameters to provide for defined situations. An immediate question to resolve is whether 6 degrees of freedom is more desirable than 5 or 4 in light of the ability to install them satisfactorily? Operating practices have most often settled for four or less axes. There is the strong suggestion in the literature that fewer motion axes (e.g., two) augmented by other motion cues will yield quite satisfactory results for purposes of training. For example, the employment of cockpit tilting to augment the physical motion which is introduced and then faded back after a short time duration may have useful cue value. The same may be said for applying pressures on critical body points as motion cues. In total, the requirement is for a programatic study of the available motion parameters and values for representative aircraft tasks. The study should be accomplished with operational simulation equipment.

d. Allied to (c) above, is the need for systematic research on visual and motion interactions in flight simulation. There are ample suggestions from operating practice that when a high fidelity visual display is coupled with rudimentary or even imprecise physical motion, the pilot feels he is in a moving vehicle. For example, anecdotal evidence indicated that a random heaving motion coupled with high fidelity displays will achieve substantial task fidelity. The goal is to put into perspective the options available in backing off from total motion simulation to achieve training objectives. Similarly, data are needed which test the validity of less than precise fidelity in motion representation, i.e., what are the cue value relationships?

Related to this area is the effect of optical distortion in performance. Visual (apparent) motion that is distorted (i.e., inexact simulation of the visual cues which occur in operational flight) has been cited as the cause of nausea and dizziness in the device 2-FH-2 Hover Trainer and not due to the conflict between visual and motion cues (Miller and Goodson, 1958). Gibson (Horowitz, 1964) states that the geometry of motion perspective is not well worked out. It may be of some value to develop principles for partialing out optical distortions in the coupling of visual and motion dynamics in flight simulators.

e. The issue of the scaling down of motion forces in simulator design is of some concern. Partial force simulation involving a reduction in the dynamic range required of the motion platform appears to be a desirable design option, particularly in a high fidelity visual display and platform motion coupling context. Basic data and design principles, however, are lacking, and research is needed to place the design relationships into perspective. Of some interest is the validity of objective performance measures in the scaled down motion cue environment and the transfer of training effects of this simulated environment to the actual aircraft.

f. A desirable effort is a study which organizes and collates, in guideline form, the design procedures found to be currently most successful in motion platform construction as practiced by simulator manufacturers. This should be undertaken for a variety of task requirements for both training and research simulators and with the recognition of the proprietary interests involved.

g. Enough evidence has been assembled that indicates that motion can be induced by techniques other than moving the entire cockpit on a platform. Since man has difficulty in distinguishing between vestibular and somesthetic sensations, subjectively valid motion cues may usefully augment the platform motion. Auxiliary devices, such as: 1) computer controlled pneumatic seat cushions and restraining devices such as harnesses and seat belts, and 2) the use of shearing forces, i.e., stimulation of touch and pressure points on the skin, may provide additional effects of sustained acceleration meaningful to the man. Quantitative relationships should be developed for the employment of these techniques in sophisticated training devices. Again, operational simulation equipment should be utilized in these investigations.

h. Basic data are needed on vibration thresholds over the pertinent range of frequencies and task and maneuver requirements. These data should be obtained on operational simulation equipment. In addition, studies should be undertaken to determine the effects of random uncorrelated vibrating motion on performance. It is also reasonable to determine the transfer of training of uncorrelated motion vs. correlated motion to the actual aircraft.

i. A review study is desirable, tailored for the human factors specialist responsible for training device design, which places into perspective issues of spatial disorientation, illusions of movement and nausea that are attributable to simulator design but not correlated with events in the operational environment. Guidelines should be organized to call attention to, and to develop means for minimizing these artifacts in design.

j. It is noted as a general observation that a proportionally large number of motion studies have been concerned with comparisons of motion with no motion on performance in the simulator. Obviously, it would be desirable to acquire a transfer of training data base using the motion-no motion paradigm with operational simulation equipment and the operational aircraft.

3.3 VEHICLE CONTROL REQUIREMENTS[1]

This chapter considers human factors design requirements for simulating aircraft vehicle control. The basic issues concern the design options available for achieving transfer of training and center on the relationships of simulation conditions to training effectiveness. Two quite opposite viewpoints are currently held. One approach assumes that the desired design is one wherein the simulated controls are made to match vehicle controls as close as possible (i.e., the best training simulators bear the closest physical resemblance to the aircraft). The capabilities and the relatively reasonable costs of current high speed digital computers support this concept of complex simulation. Algebraic operations are easily accomplished in the digital computer, hence there is a tendency to include a great many terms in the relevant equations, even though the effects of many of them may be unknown or quite negligible for training purposes.

The opposite approach suggests that a reduction in physical fidelity of simulation (e.g., omission of terms in the equations) can be accomplished without significantly affecting trainee performance. Systematically reducing the level of aerodynamics simulation while not compromising performance, introduces significant economies in computer hardware and associated software programing. Additionally, it is desirable to depart from fidelity of simulation to provide additional cues supportive of training but not found in the operational system. Assuming cost minimization as a goal, design and fabrication costs may be reduced by subtracting unneeded simulator fidelity from a contemplated design, and utilization costs may be reduced by adding extra cues to the simulator which will enhance the transfer of training or reduce the training time.

Although current and future computation capabilities encourage design of simulated controls which duplicates the characteristics of the operational aircraft, the discussion in this chapter centers on the alternative approach, that of backing off from fidelity without compromising training effectiveness. The material presented concerns the following topics:

- the purpose of simulator controls (as distinct from aircraft controls)
- desired control fidelity
- evaluative criteria for simulator controls
- research issues.

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[1] This chapter was prepared by Dr. Herbert Smithline of Dunlap and Associates, Inc.

3.3.1 Purpose of Simulator Controls. Though they may appear to have the same purpose, the controls of an aircraft serve a fundamentally different purpose than the controls of a simulator. Very simply, the controls of an aircraft are designed to guide the aircraft; but the controls of a simulator are designed to train the student. Thus, the designer need not hesitate to deviate from physical fidelity if by so doing, equivalent training is accomplished at lower costs.

For training purposes, the student is taught to do with the simulator controls what the skilled pilot does with the aircraft controls. Aircraft controls serve a dual purpose. They are used to alter the state of an aircraft, or they are used to maintain the status of an aircraft in spite of disturbing forces. McDonnell (1968) states that, control implies the imposition of commands on the system and also the suppression of disturbances. The inputs of the pilot to the aircraft may be pure commands (which are functions of time alone) or may depend on some vehicle deviation from a desired state of motion; so command operations are open- and closed-loop in nature. Although the open-loop characteristics can have a large influence on pilot workload, ratings (of handling qualities) tend to depend on closed-loop control characteristics because most deficiencies appear only under these conditions.

3.3.1.1 Kinds of Tasks. The pilot trainee is called upon to engage in continuous interactive tasks as well as non-interactive sequential procedures. The training simulator controls should assist the pilot to perform successively more complex closed-loop tasks, as well as to progressively improve his selection and interleafing of required open-loop tasks. Design should be more concerned with dynamic control response for closed-loop tasks; while control location and configuration should be the concern for the open-loop variety. This is not to suggest that the demarcation between open- and closed-loop behavior is always clear-cut. Skillful behavior is essentially closed-loop initially. However, as skill increases, behavior takes on the characteristics of open-loop behavior, as there is progressively less need for feedback. That is, the checking and correcting feedback is required only on an intermittent basis, and simple skillful acts may be chained without conscious feedback for each simple act.

3.3.2 Control Fidelity. A popular belief is that the best simulator is the one which most perfectly matches the simulated aircraft, hence it would be assumed that simulator controls should match vehicle controls as closely as possible. However, perfect physical fidelity does not necessarily enhance training value, particularly in the earlier stages of training. Optimum transfer of training is promoted by devices and situations which provide: guidance for desirable behavior, knowledge of the results of performance, reinforcement of proper behavior, motivation for the trainee, and also encourage the development of a learning set. Obviously, it is desirable in some cases to depart from aircraft fidelity to provide special cues and other supports to achieve training goals. In addition, it may be desirable to retreat from full aircraft fidelity to realize savings in simulator design and fabrication costs, particularly if the additional costs are incurred with no practical increase in perceptual equivalence.

3.3.2.1 Fidelity for Purposes of Training. As noted above, fidelity of simulator controls to aircraft controls is not a primary goal; whereas adequate transfer of training is, thus, it is often quite desirable to depart from physical fidelity to achieve the desired transfer effects. Since training is facilitated if easier tasks lead to difficult ones, and the ease or difficulty of a task may be influenced by simulator control characteristics, the following kinds of deviations from realism are beneficial to the training process:

- quickening the response to control motion so that a trainee can more readily see errors and correct them
- adding special cues to the "feel" of the controls (for example, artificial, i.e., nonrealistic, control vibration may be used to shape trainee responses)
- adjusting the control gain to make the simulator fly more easily than the aircraft it represents.

In fact, control characteristics may be automatically modified as a function of trainee performance level as a means of achieving adaptive training. In adaptive simulation, the task can be manipulated by modifying the external forcing function. Here it is suggested that the task may be altered by modifying the control dynamics, e.g., by shortening system response time.

In addition to adding artificial cues to the operation of the controls to facilitate transfer of training, control cues may be augmented so that a novice could be taught to perceive what a veteran recognizes as significant in the feel of the controls.

3.3.2.2 Motivational Benefits of Realistic Controls. Good perceptual fidelity of the controls adds a great deal of face validity to the training situation, especially for the advanced student who has had substantial exposure to the aircraft being simulated. As long as a trainee can say, "...all exercises up to date have felt more like playing darts than flying an aeroplane..." (Craik, 1966), he will not be properly motivated for the training experience. In evaluating pilot ratings of handling qualities, McDonnell (1968) found that the ratings were primarily based on 1) simulator performance, 2) required pilot equalization, and vehicle stick characteristics. Orlansky (1948) reported that experienced fighter pilots rated horizon reference and stick feel as the primary sources of cues during many maneuvers. A stick with feel is equivalent to a host of flight instruments. Accordingly, it is not surprising that if the controls do not feel right to an experienced pilot, his confidence in the simulator will be undermined to such an extent that his training will be hindered. It behooves the designer therefore, to provide simulator controls that can be set to feel like those of the aircraft. At times in the training cycle, particularly early in the cycle, it may be desirable to make the simulator controls "easy," or incorporate special cues but at some point the trainee has to be motivated by the knowledge that he is experiencing a faithful representation of the aircraft. In a subsequent section we shall discuss the important factors for perceptual (not physical) fidelity. First, however, factors other than "feel" that can affect the usefulness of simulator controls are discussed.

3.3.2.3 Fidelity of Configuration. In addition to improper "feel," trainees tend to be disturbed by controls which are not configured correctly (e.g., because the simulator represents a model of the aircraft older than the one with which pilot is familiar). As a practical matter, to maximize positive transfer, design should consider the use of modularized or otherwise easily reconfigurable control elements. Improperly configured controls can have a negative effect on trainee attitude.

3.3.2.4 Fidelity Requirements for Interactive Tasks. Much of a trainee's time in a flight simulator is spent on closed-loop tasks. He learns to maintain the condition of the simulated aircraft despite disturbing forces, or he learns how to alter the condition from state-to-state in a properly controlled manner. Current simulators are capable of a wide range of control characteristics to support the training procedure. Circuits can produce accurate overall force gradients and also represent such mechanical features as hysteresis, dead-band, and stick vibration. Simulator designers have become increasingly able to duplicate the physical world in a simulator, though at increasing costs. The question naturally arises, can some physical fidelity be dispensed with, without sacrificing perceptual equivalence. For example, Demaree, Norman and Matheny (1965) state that the rising cost of providing high simulation fidelity makes it imperative that studies be conducted in an effort to determine acceptable levels of reduction in fidelity with accompanying reductions in simulation costs. In the following paragraphs, we shall discuss closed-loop task fidelity as it is affected by the aerodynamic equations, the calculation of equation parameters, and the program cycle time.

3.3.2.4.1 Simplification of Aerodynamic Equations. Studies have attempted to ascertain perceptually significant characteristics of a simulator. A representative example is the work of Wilkerson, Norman, Matheny, Demaree, and Lowes (1965), which demonstrated that the aerodynamic equations of the simulated aircraft (and hence the motions and forces on the controls) may be simplified for training purposes. They set to zero such terms as the thrust contribution to pitching moment, product of inertia contribution to yaw rate, etc. The results favoring the use of simplified aerodynamic equations are qualified, however, with the recommendation that the findings should be confirmed on a moving base simulator, involving realistic flight segments (e.g., landing approach maneuvers) with turbulence.

Given the aerodynamic equations, Wilkerson, et al (1965) and Ellis, et al. (1968), found that reduced simulation conditions resulting from use of rigid airframe aerodynamic coefficients may well be adequate for training. However, straight line, least square approximations to the flexible coefficients were found to be not feasible. For convenience of the reader, summaries of their findings are shown below. Table 23 shows the development of complete and incomplete aerodynamic equations. Tables 24 and 25 indicate the kinds of errors in longitudinal and lateral parameters which may be tolerated (column headed "Rigid") and which may not be tolerated (column headed "Least Squares"), so far as their effect on transfer of training is concerned.

3.3.2.4.2 Increasing Program Cycle Time. In addition to modifying the aerodynamic equations used, fidelity may be reduced and simulator cost decreased by increasing the program cycle time. Program cycle time refers to the repetition interval for the exchange of data between the computer and the (simulated) cockpit, and for the solution of the simulation equations. (Wilkerson, et al, 1965) The shorter the cycle time, the greater the fidelity possible in a simulator. Cycle times used covered the range of 33.3 to 83.3 msec. Hunt (1967) discusses the short cycle time for a particularly difficult control simulation. "An example of an unusual control force domain is the simulation of the force characteristics of the control yoke fore and aft motion on an unboosted spring tab elevator system when the aircraft is on the ground and the tab has no aerodynamic effect. In this example, the problem arises from the complicated sequence of mechanical linkage pickup and snubbing actions occurring throughout the total travel of the control yoke with attendant abrupt inertia changes reflected to the control column. In attempting to provide realistic simulation of control forces throughout all foreseeable operating conditions, the designer of a control force system must provide a servo with unusual dynamic characteristics. The closed-loop response of such a system is controlled by computer-generated parameters, is exceedingly nonlinear, and involves closed-loop frequencies as high as thirty cycles per second." (p. 44.) More reasonable cycle times of 50 msec. were set for the Universal Digital Operational Flight Trainer Tool (UDOFTT) developed by the U.S. Naval Training Device Center and the U.S. Air Force. However, Wilkerson, Norman, Matheny, Demaree and Lowes (1965), found that the program cycle time for the UDOFTT could be increased to 83.3 msec. for many training purposes, using the O_{33} Mod Gurk integration formula. Their work indicated that other integration formulas might permit further lengthening of program cycle time though they did not suggest an upper bound to cycle time. As a limit, we might expect that the cycle time could probably not be increased beyond 125 ms.

3.3.2.4.3 Control Types. The previous discussion indicated that aerodynamic equations and their implementation affect feedback to the trainee directly through his controls as well as through other avenues (e.g.,

TABLE 23. COMPLETE AND INCOMPLETE AERODYNAMIC EQUATIONS[1]

Acceleration Along X - Wind Axis

Complete Equation:

$$A_x = \frac{1}{m} \left[- qs \{f_2 (M) + [f_5 (M) + f_6 (M) f_7 (C_L)] C_{L_i}{}^2\} + T_n - W_G \sin \gamma \right].$$

No Change

Acceleration Along Y - Wind Axis

(Aerodynamic and Thrust Components Only)

Complete Equation: $K_1 = K_2 = K_{14} = 1$

$$A_{y_a} = \frac{1}{m} \left[qs \{- f_9 (M) \beta + K_1 f_{10} (M) \delta_r - K_{14} f_{11} (M) \delta a_{TOT} \} - K_2 T_N \cos \alpha \sin \beta \right].$$

Incomplete Equation: $K_1 = K_2 = K_{14} = 0$

$$A_{y_a} = \frac{1}{m} \cdot qs [- f_9 (M)] \beta.$$

K_1 : Contribution to side force due to rudder deflection

K_2 : Thrust component term

K_{14} : Contribution to side force due to aileron deflection

[1] The complete equations were developed by the manufacturer of the airplane which was simulated and the incomplete equations were developed by Castellano (In Press).

TABLE 23. COMPLETE AND INCOMPLETE AERODYNAMIC EQUATIONS [1] (continued)

Acceleration Along Z - Wind Axis

(Aerodynamic and Thrust Components Only)

Complete Equation:

$$A_{z_a} = \frac{1}{M}\left[- qs\ C_L - T_N \sin \alpha\right].$$

No Change

Roll Acceleration About the X - Body Axis

Complete Equation: $K_3 = K_4 = K_5 = K_{11} = 1$

$$\dot{p} = \Big\{\frac{M_{x_s} \cos \alpha - M_{z_s} \sin \alpha}{I_{xx}} + K_4\ \frac{(I_{yy} - I_{zz})}{I_{xx}}\ q_1\ r + K_5\ \frac{J_{xz}}{I_{xx}}\ p\ q_1 + \left[\frac{M_{z_s} \cos \alpha + M_{x_s} \sin \alpha}{I_{zz}} + \frac{(I_{xx} - I_{yy})}{I_{zz}}\ pq_1 - K_{11}\ \frac{J_{xz}}{I_{zz}}\ q_1\ r\right] K_3\ \frac{J_{xz}}{I_{xx}}\Big\} \left\{1 - K_3\ \frac{{J_{xz}}^2}{I_{xx}\ I_{zz}}\right\}^{-1}.$$

Incomplete Equation: $K_3 = K_4 = K_5 = K_{11} = 0$

$$\dot{p} = \frac{M_{x_s} \cos \alpha - M_{z_s} \sin \alpha}{I_{xx}}$$

K_3 : Product of inertia contribution to roll rate.

K_4 : Moment of inertia contribution to roll rate.

K_5 : Product of inertia contribution to roll rate.

K_{11} : Product of inertia contribution to yaw rate.

TABLE 23. COMPLETE AND INCOMPLETE AERODYNAMIC EQUATIONS[1]
(continued)

Rolling Moment About the X Stability Axis

Complete Equation: $(K_6 = 1)$

$$\begin{aligned} M_{x_s} = qsb\ \{&[-f_{19}(M) - f_{20}(M)\, f_{21}(h)]\ \beta \\ &+ [-f_{23}(C_L) - f'_{23}(C_L) - f_{24}(C_L)\, f_{25}(M)]\,[1-f_{35}(M)\, f_{36}(h)]\ \delta_{aTOT} \\ &+ [f_{26}(M) - .00052\, C_L]\,[1-f_{37}(M)\, f_{38}(h)]\ \delta_r \\ &+ [-f_{27}(M)+f_{29}(C_L)\, f_{30}(M) - f_{28}(C_L)]\,[1-f_{39}(M)\, f_{58}(h)]\ \frac{b}{2(1117)M} \\ &\qquad (p \cos\alpha + r \sin\alpha) \\ &+ K_6\, [f_{32}(C_L)]\,[1-f_{39}(M)\, f_{58}(h)\ \frac{b}{2(1117)M}\,(r\cos\alpha - p\sin\alpha)\}. \end{aligned}$$

Incomplete Equation $(K_6 = 0)$

$$\begin{aligned} M_{x_s} = qsb\ \{&[-f_{19}(M) - f_{20}(M)\, f_{21}(h)]\ \beta \\ &+ [-f_{23}(C_L) - f'_{23}(C_L) - f_{24}(C_L)\, f_{25}(M)]\,[1-f_{35}(M)\, f_{36}(h)]\ \delta_{aTOT} \\ &+ [f_{26}(M) - .00052\, C_L]\,[1-f_{37}(M)\, f_{38}(h)]\ \delta_r \\ &+ [-f_{27}(M) + f_{29}(C_L)\, f_{30}(M) - f_{28}(C_L)]\,[1-f_{39}(M)\, f_{58}(h)]\ \frac{b}{2(1117)\,M} \\ &\qquad (p\cos\alpha + r\sin\alpha)\}. \end{aligned}$$

K_6 : Contribution to roll moment due to turning rate.

Yaw Acceleration About Z - Body Axis

Complete Equation: $K_{11} = 1$

$$\dot{r} = \frac{M_{z_s}\cos\alpha + M_{x_s}\sin\alpha}{I_{zz}} + \frac{(I_{xx} - I_{yy})}{I_{zz}}\, pq_1 + \frac{J_{xz}}{I_{zz}}\,\dot{p} - K_{11}\,\frac{J_{xz}}{I_{zz}}\, q_1 r\ .$$

Incomplete Equation: $K_{11} = 0$

$$\dot{r} = \frac{M_{z_s}\cos\alpha + M_{x_s}\sin\alpha}{I_{zz}} + \frac{(I_{xx} - I_{yy})}{I_{zz}}\, pq_1 + \frac{J_{xz}}{I_{zz}}\,\dot{p}\ .$$

K_{11} : Product of inertia contribution to yaw rate.

TABLE 23. COMPLETE AND INCOMPLETE AERODYNAMIC EQUATIONS[1]
(continued)

Yawing Moment About the Z - Stability Axis

Complete Equation: $K_{13} = 1$

$$
\begin{aligned}
M_{zs} = qsb \{ & [f_{60}(M) + f_{61}(h)\, f_{62}(M)]\, \beta \\
& - [f_{63}(M) + f_{64}(h)\, f_{65}(M)]\, \delta_r \\
& + .4\, [f_{70}(M)\, f_{72}(C_L)]\, \delta_{aTOT} \\
& - [f_{74}(M) + f_{75}(h)\, f_{76}(M)]\, \frac{b}{2(1117)M}\, (r \cos \alpha - p \sin \alpha) \\
& - K_{13}\, f_{80}(C_L)\, [1 - f_{81}(M)\, f_{82}(h)]\, \frac{b}{2(1117)M}\, (p \cos \alpha + r \sin \alpha) \}.
\end{aligned}
$$

Incomplete Equation: $K_{13} = 0$

$$
\begin{aligned}
M_{zs} = qsb \{ & [f_{60}(M) + f_{61}(h)\, f_{62}(M)]\, \beta \\
& - [f_{63}(M) + f_{64}(h)\, f_{65}(M)]\, \delta_r \\
& + .4\, [f_{70}(M)\, f_{72}(C_L)]\, \delta_{aTOT} \\
& - [f_{74}(M) + f_{75}(h)\, f_{76}(M)]\, \frac{b}{2(1117)M}\, (r \cos \alpha - p \sin \alpha) \}.
\end{aligned}
$$

K_{13} : Contribution to yaw moment due to roll rate.

Pitch Acceleration About the Y - Body Axis

Complete Equation: $K_7 = 1.$

$$\dot{q}_1 = \frac{M_{ys}}{I_{yy}} + \frac{(I_{zz} - I_{xx})}{I_{yy}}\, pr + K_7 \frac{J_{xz}}{I_{yy}} (p^2 - r^2).$$

Incomplete Equation: $K_7 = 0$

$$\dot{q}_1 = \frac{M_{ys}}{I_{yy}} + \frac{(I_{zz} - I_{xx})}{I_{yy}}\, pr .$$

K_7 : Product of inertia contribution to pitch rate.

TABLE 23. COMPLETE AND INCOMPLETE AERODYNAMIC EQUATIONS[1] (continued)

Pitching Moment About the Y - Stability Axis

Complete Equation: $K_8 = K_9 = 1$

$$
\begin{aligned}
M_{y_s} = q s \bar{c} \{ & f_{40} (M) + [- f_{46} (M) - f_{47} (h) f_{48} (M) + \frac{c.g.\%}{100}] C_{L_i} \\
& + [- f_{51} (M) - f_{52} (M) f_{53} (h)] \frac{\bar{c}}{2(1117) M} q_1 \\
& - [f_{54} (M) + f_{55} (h) f_{56} (M)] \delta_{is} \\
& + K_8 [f_{57} (M) - f_{49} (h) f_{50} (M)] \frac{\bar{c}}{2(1117) M} \frac{\dot{\alpha}}{57.3} \} \\
& - .0833 K_9 T_N.
\end{aligned}
$$

Incomplete Equation: $K_8 = K_9 = 0$

$$
\begin{aligned}
M_{y_s} = q s \bar{c} \{ & f_{40} (M) + [- f_{46} (M) - f_{47} (h) f_{48} (M) + \frac{c.g.\%}{100}] C_{L_i} \\
& + [- f_{51} (M) - f_{52} (M) f_{53} (h) \frac{\bar{c}}{2(1117) M} q_1 \\
& - [f_{54} (M) + f_{55} (h) f_{56} (M)] \delta_{is} \}.
\end{aligned}
$$

K_8 : Contribution to pitching moment from rate of change of angle of attack.

K_9 : Contribution of thrust to pitching moment.

(from Wilkerson, Norman, Matheny, Demaree and Lowes, 1965)

TABLE 24. PERCENTAGE CHANGES IN LONGITUDINAL PARAMETERS

Parameters	Rigid	Least Squares
M_α	+ 16.5%	- 30.75%
$M_{\delta_{is}}$	+ 20.0%	- 8.3 %
Z_w	+ 7.5%	- 10.0%
M_q	+ 22.0%	- 8.0 %
* $\left(\frac{q_1}{\delta_{is}}\right)_{ss} = \frac{M_{\delta_{is}} \; Z_w}{M_\alpha}$	+ 10.5%	+ 18.5 %
f_{sp} (O.L.)	+ 8.0%	- 16.7 %
f_{sp} (C.L.)	+ 6.0%	- 12.0 %

* Pitch rate change per unit elevator deflection in the steady state.

(from Ellis, Lowes, Matheny and Norman, 1968)

TABLE 25. PERCENTAGE CHANGES IN LATERAL PARAMETERS

Parameters	Rigid	Least Squares
N_β	+ 72%	- 30.7%
L_p	+ 27%	+ 7 %
$Y_v + N_r$	+ 106%	+ 3 %
L_{δ_A}	+ 125%	+ 53 %
* $\left\lvert \frac{P}{\delta_A} \right\rvert_{ss} = \frac{L_{\delta_A}}{L_p}$	+ 50%	+ 27.5%
$\left\lvert \phi / \beta \right\rvert$	- 41.8%	+ 17.6%
ζ_{DR}	+ 57%	+ 24 %
f_{DR}	+ 35%	- 19.5%
τ_p	- 27.5%	- 21.8%
τ_s	- 1.5%	- 20 %

* Roll rate per unit aileron deflection in the steady state

(from Ellis, Lowes, Matheny and Norman, 1968) instrument readings, platform motion and visual displays). In this paragraph, controls are discussed in more detail by reviewing several classes of controls, the mathematical relations that describe their action and some of the facts known about the sensitivity of man in operating the more important types of controls. Kelley (1968) subdivides controls into "force operated" controls and "positioning" controls. Some of the important differences between these two types of controls are described by Kelley:

Force Operated	Position Operated
1. Control forces correspond to forces applied by operator; "natural" control.	1. Control forces do not correspond to forces applied by operator; interpretive step required for control.
2. Control lever is self-centering; forces diminish to zero unless manual force is maintained on the control.	2. Control lever remains at position on which placed; forces remain applied without maintaining manual force on the control.
3. A large range of forces may be accurately controlled in a small range of control lever displacement.	3. To control a large range of forces accurately, a large range of control lever movement is needed.
4. To control a large range of forces accurately, large amounts of manual force are required.	4. A large range of forces can be controlled accurately with very small manual forces.
5. Because of (4), to control a large range of forces accurately, a control must be built and located so the operator may exert large manual forces on it.	5. Because of (4), a large range of forces can be controlled accurately by many types of controls, involving very slight forces, and placed in a large range of locations.

Free positioning controls usually maintain a set position by virtue of sliding friction, and the operator senses the position of his body members. The forces required to move the control are too small to result in significant feedback. Force operated controls require greater force and the feeling of the applied pressure provides useful feedback. The force operated controls may be subdivided into several groups. For a rigid type of control with strain gage pickup, the feedback to the operator is simply the pressure resulting from the amount of force he applies. For a simple spring loaded type of control, motion is proportional to the amount of force, and the operator senses both pressure and position. Viscous controls move at a velocity proportional to the applied force, and they remain displaced when the applied force is zero. Finally, inertial controls accelerate at a level proportional to the applied force, and when the force is removed they continue to move at a constant rate. Each of the four categories of force operated controls may be considered as idealized categories. Any actual aircraft or simulator force control may be considered as a combination of four types, and the operator senses force level, position, velocity and acceleration. If we take X as the displacement of force control, resulting from an applied force, f, then the following relationships apply:

$X = k_1 f,$ for the spring loaded case

$\dot{X} = k_2 f,$ for the viscous case

$\ddot{X} = k_3 f,$ for the inertial case

where k_1, k_2, and k_3 are constants of proportionality.

The control, whose response is not purely inertial, viscous or spring loaded, may be described by the relation

$$f = a + bX + c\dot{X} + d\ddot{X}$$

where: f is the force exerted by the control

X is the displacement for some arbitrary reference position

$\dot{X}$ is the velocity of the control

$\ddot{X}$ is the acceleration of the control

a is the force exerted at the reference position

b, c, d are the factors which relate displacement, velocity, and acceleration on control force.

The significance of the general relationship shown above is that two controls will feel alike if the equations describing their motion have the same values of a, b, c, and d. Alternatively, the same control will be described by different values of a, b, c, and d under different flight conditions. Hence, it will feel different under different flight conditions. To say that a simulator control feels like that of an aircraft's is tantamount to saying its values of a, b, c, and d are the same as the aircraft's under different conditions of simulated flight.

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Up to this point, we have been discussing the simple case where a control is free to move in one direction. The above relationship may be extended in a straightforward way to describe more complex controls, e.g., a yoke. Thus,

$$f = a + bX + c\dot{X} + d\ddot{X} + e\alpha + f\dot{\alpha} + g\ddot{\alpha}$$

where most of the terms are as previously defined, but

α is the rotational displacement of the control from an arbitrary reference position

$\dot{\alpha}$ is a rotational velocity of the control

$\ddot{\alpha}$ is the rotational acceleration of the control

a is the force exerted at the reference position for displacement and rotation.

Although the two yokes may feel the same if their values of a, b ... g are the same under different flight conditions, the designer is faced with the inevitable question of how much deviation can be tolerated without being noticed by the trainee. The designer is interested in the question of psychophysical discrimination for two reasons. First, he would like to know "what he can get away with" when trying to duplicate an aircraft's controls. Second, he would like to know, how much control force enhancement is required in developing the necessary training cues.

3.3.2.4.4 Force Levels. Pilot control forces in realistic situations are difficult to duplicate in the laboratory. However, some guidance concerning perceptually significant differences in control force levels is provided from the work of Jenkins (1947).

Difference Limens for 20 Pilots Reproducing Aircraft Control Forces

Standard Pressure (lbs)	Stick Control	Wheel Control	Rudder Pedals
1	.20	.23	-
5	.10	.09	.10
10	.08	.07	.07
20	.08	.06	.05
30	.07	.06	.05
40	.06	.05	.04

He found that the difference limens or Weber fraction (standard deviation divided by reference force) was about .20 at the one pound force level and decreased to .07 at the 10 lbs. force level. About 10 lbs. of force, the Weber fraction remained at about .06. Jenkins also found that just resting a hand on a control was equivalent to about 1 lb. of force, and resting a foot on a simulated rudder yielded a force of 5 lbs. which implies that discrimination of forces below those levels should be avoided in design considerations.

3.3.2.4.5 Effective Time Constant. The effective time constant, t_e, is a useful construct to compare simulator and aircraft controls. It is also a useful measure on which to base simulator control modifications during the training period, since t_e is related to task difficulty. This construct was used by Matheny and Norman (1968) to describe the delay in speed of feedback to an operator who has made a control input. The effective time constant describes the entire man-machine system but is strongly influenced by such control factors as gain and damping parameters. Matheny and Norman (1968) define t_e as "...the time interval from the initiation of a one-inch step displacement of the control stick, measured at the top of the stick, to the time at which the display member has been displaced through .4 degrees of arc from its initial position, measured at the position of the operator's eye." (p. 2.)

Regardless of the system order, the value of t_e is affected by a number of different factors. A first order system may be described by the relationship:

$$y_o(t) = \kappa\,(1 - \varepsilon^{-t/\tau})$$

where: $y_o(t)$ is system output as a function of time

κ is system steady state gain

t is time

τ is the time constant

t_e is affected by (or may be controlled by) the values of κ, τ, and the threshold value of $y_o(t)$.

A second order system may be described by the equations:

$$y_o(t) = \kappa \left[1 + \frac{1}{d}\, \varepsilon^{-\zeta w t}\, \mathrm{sm}\left(\omega d t - \arctan \frac{d}{-\zeta} \right) \right]$$

$$d = \sqrt{1 - \zeta^2}$$

where:
$y_o(t)$ is system output as a function of time
κ is system steady state gain
ω is the undamped natural frequency
ζ is the damping ratio
t is time
d is the damping factor, defined above as a function of ζ.

From the second order system equations, it is apparent that t_e is controlled by κ, ω and ζ, in addition to the threshold value of $y_o(t)$.

Matheny and Norman (1968) observed that lower values of t_e resulted in an easier closed-loop task. The relationship seemed linear between t_e and performance when a logarithmic transformation was used for t_e. They also observed that for untrained people the product κt_e was directly related to task difficulty. That is, for a given level of t_e, lowering the value of κt_e simplified the tracking task for unskilled personnel.

The designer may therefore wish to have the system gain, natural frequency and damping ratio (and hence t_e) controllable, and often different from that of the aircraft simulated. To assist the transfer of training, the values of κ and t_e might be set lower than the "true" levels. Later, as skill improved, the values could be raised to normal levels or possibly to above-normal levels.

3.3.3 Evaluation Criteria. This paragraph summarizes points already discussed and may serve as a checklist for the designer in evaluating a set of simulator controls (i.e., when the more fundamental bounds of the design effort have been established). In evaluating the simulator controls, the following points should be considered:

- Are the controls designed with the intent of optimizing training, rather than merely duplicating the aircraft's controls as closely as possible?
- Can the controls be adjusted to make flying the simulator easier than flying the aircraft by adjusting such things as gain, effective time constant, enhancement of natural cues, etc.?
- Are the controls capable of supplying "artificial" cues to the trainee?

- Within their performance envelope, are the controls capable of duplicating those of the aircraft with a high degree of perceptual fidelity to help motivate the advanced student? Some of the control parameters to be considered are control force, position, viscous and inertial response, gain, and effective time constant. (For most of these parameters the designer will have to use judgment as to what is "close enough" to reality; Tables 24 and 25 indicate the kinds of errors in the aerodynamic equation parameters which may be tolerated).
- Are the controls amenable to adaptive training techniques?
- Are the controls configured like those of the simulated aircraft; can the controls be readily reconfigured to duplicate different versions in the aircraft design?
- Are the controls designed to minimize total training costs, i.e., simulator design and fabrication costs as well as training time costs?

3.3.4 Research Issues. Several research issues of priority for human factors design are indicated next. These concern:

improving responses to natural cues

application of artificial cues

adaptive training

cost modelling development.

a) Some effort is desirable on understanding the enhancing effects of natural cues. Skilled pilots often make use of cues which are not responded to by unskilled trainees. Thus, pertinent questions for design are, which control characteristics should be heightened, when and to what extent, and when in the training cycle should the augmentation be discontinued. The proprioceptive senses are especially sensitive to changes in level rather than to the absolute magnitude of level, hence, study is suggested to determine training benefits from transformation of stick forces (or displacements) which would heighten naturally occurring changes. One possible transformation suggested is illustrated by the equation:

$$\ddot{d}_s = A\ddot{d}_t - B\dot{d}_t - Cd_t$$

where: d_s = is the displacement (or force level) of the simulator control,

d_t = is the "true" displacement, if augmentation were not incorporated,

A = the cue augmentation factor,

B,C = factors chosen to "wash out" the effect of A on d_s after a short period of time.

b) Another research issue of concern is the relationship of artificial control cues to the feedback of knowledge of performance to the trainee. Reference is made here to the use of controls which provide signals, e.g.: vibrate, as a trainee's maneuver deviates from an acceptable performance envelope; or which are difficult to operate in marked difference to the programed optimum.

c) The issue of adaptive training is also of some concern to vehicle control (see Chapter 3.6). The recommendation is to explore systematically the adjustment of task difficulty by modifying simulator control response (rather than task modification via adjustment of a forcing function, such as turbulence). This research would examine the adjustment of level of artificial cues or level of natural cue enhancement (e.g., lag or sensitivity) in accordance with trainee performance.

d) Although not directly related to this chapter, much research is needed towards establishing basic limits on training device design. There is a mounting pressure to examine the tradeoffs that may be made concerning training time in the aircraft vs. training time in the simulator. One avenue suggested is cost modeling studies to investigate the functional relationships between training value in the aircraft and in the simulator. One concern is the question, can training time in a simulator and in an aircraft be traded off linearly, i.e., k_2 hours on a simulator for one hour in an aircraft? If so, what are the limits under which this tradeoff may be made, and what is the value of k_2? Similarly, can the same kind of tradeoff be made for training time in a sophisticated simulator and in a reduced fidelity simulator, or in a simulator and in a relatively inexpensive trainer? In order to make decisions on where design and fabrication costs can best be reduced, some idea is needed on the nature of the function F_{as} and how it changes with different types of simulators and aircraft.

Illustrative of this concern for setting basic limits on simulator design, a simple cost model of the training situation is outlined below:

$$C = A_s + O_s T_s + A_a + O_a T_a$$

where C is the total cost of achieving an objective training goal

A_s is the acquisition costs of the simulator (including design and fabrication costs)

O_s is the operating costs of the simulator (including maintenance and the costs of running the simulator during training sessions)

T_s is the time spent on operating the simulator

A_a is the acquisition costs of the aircraft for training purposes

O_a is the operating costs of the aircraft

T_a is the time spent on operating the aircraft

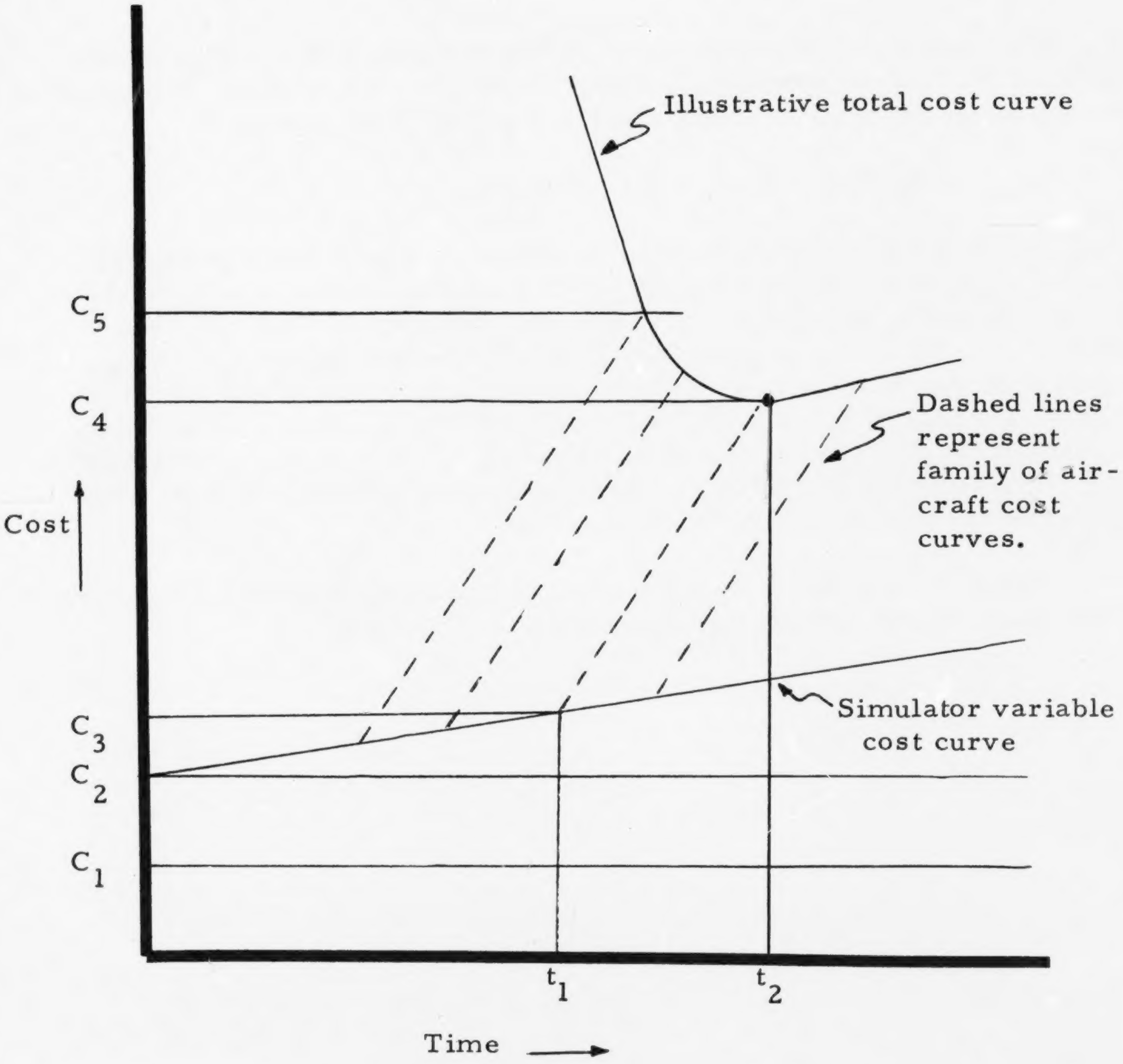
It should be noted that this cost model deals with objective costs. For example, it doesn't include the safety value of initial training on a simulator. The model also presupposes that the attainment of the training goals can be determined in some objective way, i.e., successful accomplishment of training objectives. Thus, for a given simulator and aircraft, A_s, O_s, A_a and O_a are fixed. T_s may be considered an independent variable while T_a is a dependent variable, whose length is sufficient to achieve the desired training goal with a given simulator and aircraft. The precise form of F_{as} would have to be determined empirically. However, to graphically illustrate the effect of F_{as}, Figure 36 shows the effect of using different values of T_s. Time is shown on the horizontal axis and cost on the ordinate. For minimum cost the distance between the origin and t_1 represents T_s, while T_a is represented by the distance $t_2 - t_1$; Os is C_1; O_a is $C_2 - C_1$. The minimum total cost is C_4. For the minimum cost case, $C_3 - C_2$ is the variable simulator cost, and $C_4 - C_3$ is the variable aircraft cost. A total cost which is non-minimum (because of insufficient simulator time) is shown at C_5. The slope of the line through C_2 is O_s; while the slope of the dashed lines is O_a.

For the purpose of discussion, we may assume a simple analytic representation of F_{as}. The form selected is linear and thus even more simple than the graphic representation in Figure 36, viz:

$T_a = k_1 - T_s/k_2$, when T_s is below $(k_1 - k_3)k_2$

$T_a = k_3$, otherwise.

This is equivalent to saying that the training task would take k_1 hours if the simulator were not used at all; at least k_3 hours must be spent in the aircraft, regardless of the time spent in the simulator; and k_2 hours in the simulator are equivalent to one hour in the aircraft. For this simple form



C_1-0	Fixed simulator operating cost
C_2-C_1	Fixed aircraft operating cost
C_3-C_2	Variable simulator cost for minimum total cost
C_4-C_3	Variable aircraft cost for minimum total cost
C_4-0	Minimum total cost
C_5-0	A non-minimum total cost
t_1-0	Time in simulator for minimum total cost
t_2-0	Time in aircraft for minimum total cost

Figure 36. Illustrative Total Cost Curve

of T_{as}, if it pays to use a simulator at all (essentially if $k_2O_2 < O_a$), it would pay to have the trainee spend $(k_1 - k_3)k_2$ hours in the simulator. The minimum cost of reaching the training objective would be as follows:

$$C_{min} = A_s + A_a = k_3O_a + (k_1 - k_3)k_2O_s$$

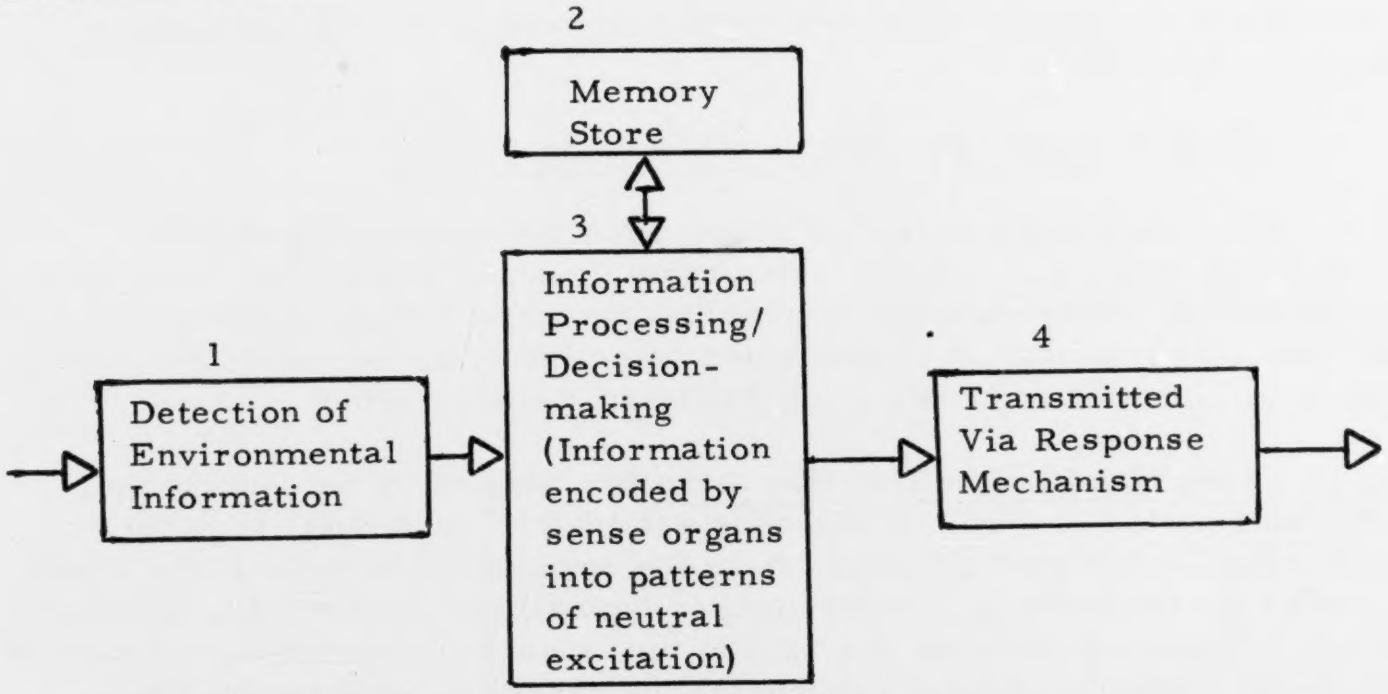
From the point of view of the simulator designer the question of whether it pays to add more realism can be considered analytically in terms of the effects on the C_{min} equation. More realism would probably tend to increase C_{min} due to the changes in A_s and O_s but tend to decrease C_{min} as a result of the changes in k_2 and k_3. Depending on the magnitude of the alternative values of A_s, O_s, k_2 and k_3, C_{min} can be calculated as raised or lowered by the increased realism. Quite obviously, if the contemplated change improved physical fidelity but not perceptual fidelity, only A_s and O_s would be affected and C_{min} would increase.

Work is required to develop this cost modeling approach, to ascertain functional forms, parameter magnitudes and the like.

3.4 INFORMATION PROCESSING.

Man/machine system performance is importantly related to the human ability to detect and to process relevant input information. Man's capacities are not limitless since he is subject to the constraints imposed by the nervous system and musculature as a function of the job requirements. Thus, knowledge of human capabilities in processing information is of importance to the design for training, particularly for optimizing design in terms of: what man can effectively do or handle in the time domain; how he processes information; and the display characteristics most suited to his capabilities.

Viewing man as a single-channel limited transmission capacity information processing system provides the potential for specifying system components most compatible with his capabilities. In simple terms, environmental stimuli impinge on man's sensory systems, a complex set of transformations are applied and a motor output is transmitted via the response system. The limited capacity of the single channel implies that when simultaneous activities each make demands on the single channel the performance of one will be at the expense of others, i.e., multiple tasks must time share the single serial channel.[1] This view of human performance attempts to describe in quantitative terms the nature of the transformations of input signals into outputs as a function of the description of the environment, the nature of the motor response and the transformations that are required (Pew, 1965). The elements of this human channel are schematized as follows:


2
Memory Store
3
Information Processing/ Decision-making (Information encoded by sense organs into patterns of neutral excitation)
1
Detection of Environmental Information
4
Transmitted Via Response Mechanism

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[1] Although there are exceptions to this view of a single channel system, it is most useful for the design of man-machine systems in that man is regarded as an information channel in the cybernetic sense rather than as an energy converter or power supply. The emphasis is on his information handling and controlling abilities (Pew, 1965).

Block 1 embraces the processes of sensation and perception. The sensory system of man transduces the inputs and codes them into patterns of neural excitation from which decisions can be made or stored in memory. Man's perceptual system is of finite capacity and incapable of analyzing simultaneously all information received by the sense organs. Only part of the total stimulation impinging on the receptors is capable of initiating a response. Thus, the issues of what man attends to in displays particularly in high information, complex formats, and how much information can he assimilate, organize and respond to are of considerable concern to the human factors design of training devices. Block 2 concerns the memory component which subsumes relatively permanent long-term storage and impermanent short-term storage. The digital computer analogy is to the random access core memory and the buffer storage, respectively. The creation of information occurs when memory is used to elaborate upon a stimulus. Broadbent (1958) has hypothesized that incoming signals are directed to the buffer storage from whence they can be further processed or stored in memory. Block 3 is concerned with man's abilities in the manipulation and combination of input and stored data. In this decision-making subsystem, the fundamental limitations on the rate of information processing occur. For the purposes of this report, we are most interested in the operations of this subsystem, for knowledge of how a man performs as a function of task makeup and how much of, and how fast he can accomplish job requirements depends on information handling rates. Block 4 is concerned with the translation of the outputs of the information processing subsystem into observable actions which effect adjustments to the environment. The limitations in man's information output rates are much less severe than the limitations imposed in Block 3.

a. Types of Human Information Processing

Quantitative prediction of information processing rate depends on task characteristics. Three forms of information processing tasks have been identified. These are tasks involving the conservation of information, tasks involving information filtering and tasks involving the condensing or reducing of information (Pew, 1965; Fitts and Posner, 1967).

Conservation of information tasks are defined by the feature that all the information in the input signal is retained in the output, thus the stimulus can be inferred precisely from the response. In these tasks where the human is a relay (e.g., typewriting is typical) the consistently relevant variable influencing performance rate is the amount of information contained in the input. Other variables influencing the rate of processing include: stimulus-response compatibility; the discriminability of input codes; and uncertainty for when the next signal will occur.

Information filtering tasks characteristically concern the monitoring/vigilance performance of man wherein he is required to examine the status of identified variables and respond only when the value of a variable(s) is in some defined critical state. In this type of task the human is utilized as a monitor.

Information condensing tasks impose the requirement for the collapsing or reduction of input information into a smaller set of output classes, i.e., the amount of information in the output is considerably less than contained in the input signals. This type of task situation, where the human functions as an evaluator is of particular importance to design in that many of the activities performed in weapons systems involve information reduction in one way or another. Information is combined from various sources or from a single source with the result being a single output operation or decision. In fact, filtering and condensing requirements are prominent in visual display interpretations, such as the sonar classification task, and Radar and EW scope analyses having high density signal and noise relationships. Information reduction is also the hallmark of tactical decision-making activities.

Our concern in this section centers on human information processing capacity as this relates to the design of training hardware. We will attempt to select from the sizeable body of research on information processing and handling those concepts and data pertinent to the selection of design alternatives. Owing to practical limitations, no attempt is made to organize systematically, data on sensory input variables, on the memory store subsystem or on the response subsystem (translation of processed information into observable actions). Each is a complex story in itself and each is well represented in the published literature.

3.4.1 Human Information Handling Capacity. Information handling capacities of the operator are definable in terms of speed and accuracy of task performance. In the framework which regards man as an information channel this is defined in terms of the amount of information transmitted per unit of time, i.e., the number of binary decisions (bits) involved in information processing. This suggests that the operator transmits information at a rate that is dependent on the particular task. When more information is transmitted in a given task, a longer time is required.

As an information link, man is capable of processing about 3 bits of information per stimulus event for any stimulus dimension. Thus, in perceptual terms, man is able to identify absolutely from six to ten steps along any physical dimension. Table 26 indicates the capacity for absolute judgment along a single dimension. Hick (1952), based on his studies, advanced the finding that response time varies as a logarithmic function of the number of alternative stimulus events. The rate of gain of information is constant. Transmission rate tends toward constancy regardless of changes in the presentation rate or information content of the stimuli. Figure 37 depicts the relationship between information processing time

TABLE 26. CAPACITY FOR ABSOLUTE JUDGMENT ALONG A SINGLE DIMENSION

Modality	Dimension	Maximum Information Transmitted (Bits)	Approximate Number of Stimuli Correctly Identified
Vision	Position on a line	3.3	10
Vision	Hue	3.1	9
Audition	Pitch	2.5	6
Audition	Loudness	2.3	5
Taste	Saltiness	1.9	4

Data taken from Attneave (1959).

and amount of information transmitted. It appears that man can trade off speed for accuracy and vice versa, so that if he is required to respond more rapidly or must attend to a greater number of stimuli at the same rate, accuracy will decrease proportionately so that the same amount of information will be transmitted.

Although the relationship of speed and accuracy tradeoffs has been demonstrated in maintaining the constancy in rate of gain of information, other variables will alter the relationship somewhat. Pew (1965) has summarized a number of variables that have been shown to affect the rate of information transmission especially in information-conservation tasks. The variables which are important to design include the following:

- The compatibility of the relationship between the input code and the output code is an important determinant of processing rate (the issue of stimulus-response compatibility is discussed later in this chapter).
- The rate of processing will be decreased if the input signal-code symbols are less than perfectly discriminable.

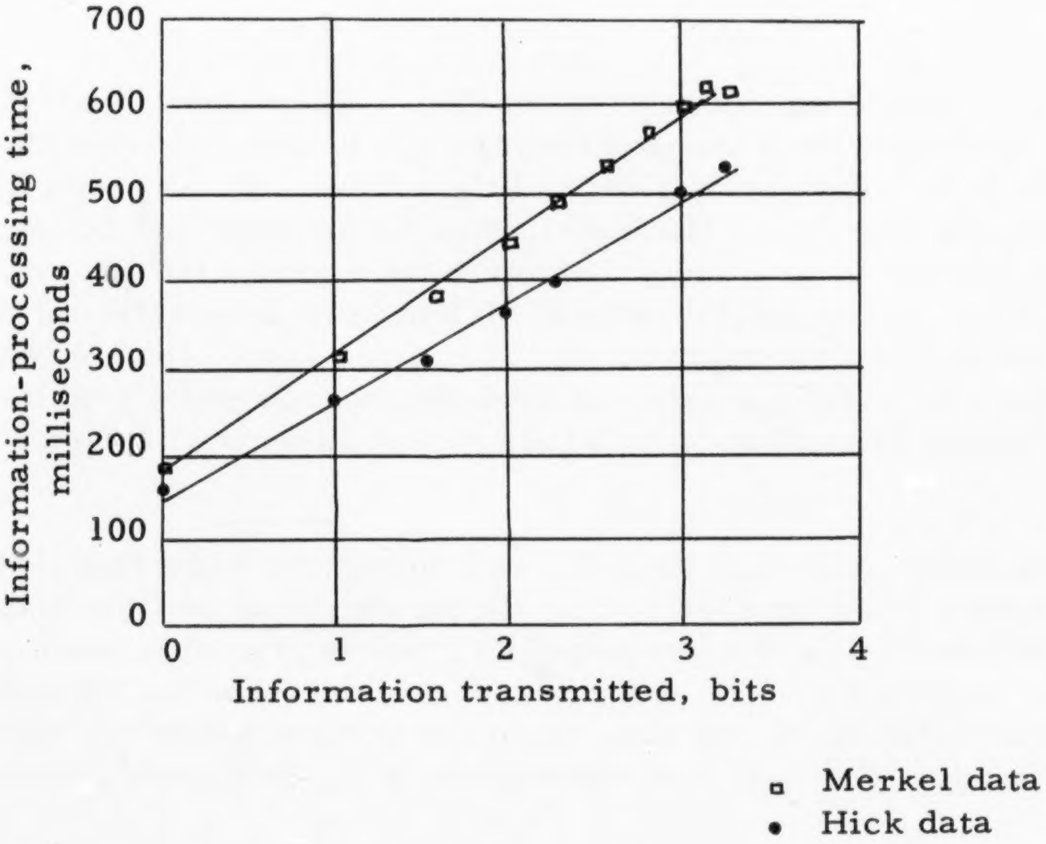


Figure 37. Data illustrating the linear relation between information-processing time and amount of information transmitted in a key-pressing task. The two curves represent two sets of data, one obtained by Merkel in 1885 and the other by Hick in 1952. The slightly different slopes and intercepts of the two curves reflect the effects of different stimulus and response codes used in the two experiments.

(from Pew, 1965)

- The operator's task set concerning which input signals will occur and when they will occur, and the relative importance of speed and accuracy on performance, affect information processing rate.
- Increasing the uncertainty as to when the next signal will occur has the effect of delaying the processing time.

For information filtering tasks (i.e., where man functions as a monitor of system events) the processing time is affected when the rate of information presentation is slow and the critical vs. no response signals are significantly different. However, when the critical and the non-critical signals are similar (e.g., needle positions on a graduated gauge), then processing time per signal increases. It has been demonstrated that the number of critical states searched for in a given signal can be as many as ten without a substantial increase in processing time per signal so long as a single response is common to all the critical aspects of a signal (Neisser, 1963).

The most important variable in information reduction tasks is the amount of information reduced in translating the input into the output. The amount of information reduction required, that is, the difference (in bits) between the input information and the appropriate response information shows a linear relation to the time required to accomplish the reduction task. The greater the reduction the slower is the processing (Posner, 1965).

3.4.2 Variables Affecting the Perceiving and Processing of Information. A series of questions important to trainee station design, particularly to the displays for training, concerns such issues as, what does the man attend to in the multi-signal and noise environment, and how does he attend to input stimuli since not all stimuli are equivalent? Allied to these is the consideration of, under what circumstances does man process information in certain ways? The data available on how man attends to and processes information has utility for design, particularly as an assist to such determinations as: how much can a man accomplish in various tasks and task conditions per unit of time; how much time does he require to complete certain activities; how does he search visual displays; what is his attention span; how does he organize and utilize high density displayed information including more than one display with or without multi-formats? Knowledge about such operations will assist in the design of displays and in the presentation of own-vehicle, target and media information.

The view of man as a single channel information processor assumes that he must time-share among competing stimuli. Thus, the variables involved in attention are of considerable interest for human factors design.

Two aspects of attention are involved: selective attention (how man attends to or notices particular parts of the displayed environment); and sustained attention (vigilance behavior--monitoring events of infrequent occurrence). For selective attention, the nature of the stimulus input is an important variable in determining how man processes information. Since all stimuli are not equivalent, selective attention is a function of: 1) the sense modality, 2) the signal characteristics (frequency, intensity, spatial location, temporal characteristics, etc.), and 3) the display characteristics (stimulus enhancement, coding, organization of data, etc.). Sustained attention is a function of the minimum input characteristics and temporal relations.

In the remainder of this subsection, design variables which affect the detection and the processing of relevant input information are discussed.

3.4.2.1 Detecting and Discriminating Visual Signals. An aspect of skilled performance is the ability to detect and identify a target from an array of stimuli or events. Questions concerning the manner in which man performs search and detection tasks or what man attends to in a multi-signal environment are of significance for design, for example, specifying the number of targets to display simultaneously or specifying the display formats in order to manage the difficulty levels of a task for training.

In visual displays, the operator must rapidly and accurately locate and identify relevant signals or events. In the visual search task he must simply scan to detect the presence/location of specific signals. In the identification task he must decode the presented information. In each case the structural characteristics of the display significantly effects performance, and dimensions such as shape, size, brightness, and hue, affect the search and decoding time. Generally, search time is increased as the number of irrelevant signals is increased. For example, Nickerson and Duva (1960), examined the discrimination of discrete dot positions in a display as a function of exposure time, display size and dot size. They found that the time available for viewing the display to be most critical. For an exposure time of 10 seconds, dot position in an imaginary 8 X 8 matrix was judged with almost perfect accuracy. Sixty-four discrete positions of a dot within a square could be satisfactorily discriminated for 10 second exposure times.

Concerning statistical aspects of signal identification, Howell and Briggs (1959) report on laboratory studies in which nonsense patterns (constructed according to statistical specifications) were used as stimuli. Subjects were required to identify figures which were altered in certain parameters. The findings suggest the following when designing visual stimulus figures to enhance recognition:

- Recognition is superior for figures constructed via a random process vs. biased procedures for obtaining nonsense forms.

- Symmetrical figures are more easily recognized than asymmetrical figures.

- Redundancy in figure construction improves performance when figures are degraded. (This, however, may be detrimental under ideal conditions.) Redundant information is helpful in stimulus recognition when noise or other distortions will occur in the situation. The use of redundant dimensions is advisable when accuracy is more important than speed of when the frequency of signal happenings is low.

- Hue is a more easily identified dimension than size or brightness in signal recognition.

- The operator utilizes only the amount of information required by the recognition task; superfluous information is detrimental.

- In tasks containing noise, a greater amount of information is necessary for successful stimulus recognition than in noise-free tasks.

An aspect of selective attention is the ability to search for and identify a target from a stimulus array. In simple laboratory task situations, the relationship between the total number of items to be searched and the time required to find the target item, is linear (Fitts and Posner, 1967). When items to be searched are letters of the alphabet, the slope of the function is about 100 milliseconds per item (Neisser, et al, 1963). The rate at which items are searched, however, depends upon the nature of the target and the surround and on the extent of display enhancement (if pertinent). As the resemblance of the target to other items increases, processing takes longer.

The question of how the operator uses displays in performing search and detection tasks is not well understood. Is the pattern of search predictable or is the search conducted randomly in saccadic fixations? Whether the approach is random or predictable, is one decidedly better than the other? Can more efficient strategies for search be taught? These and similar data are required regarding search behavior.

In addition to detecting and identifying signals, perceptual tasks require man to select certain aspects of the signal environment or determine patterns in the visual presentation. Pattern recognition plays an important part in complex skill performance since it serves to reduce the number of different stimuli to which man must attend.

3.4.2.2 Amount and Distribution of Input Information. Considerable research has been accomplished on the effects of speed and load variables on performance. Of concern here are the number of input sources to which the man must attend and the frequency and rate of event occurrence. Miller (1956) deduced that man is capable of processing about 3 bits of information for a discrete stimulus event. Based on a number of laboratory situations, the human, perceptually, is able to identify absolutely from six to ten steps along any physical dimension (Howell and Briggs, 1959; Alluisi, 1957).

In situations where a number of similar stimuli are presented simultaneously (e.g., a "dot" pattern of target blips on a radar display), evidence indicates that more than one perceptual process is involved in judging the number of targets simultaneously presented. Man is able to subitize from six to eight blips. Beyond this number, man estimates the amount, and this is manifested by an increase in the slope of the performance decrement when plotted against the number of blips presented (i.e., amount of information in the total stimulus group) (Kaufman, et al, 1949).

Experiments on the span of attention (number of items perceived simultaneously) have utilized dots to determine span limits. Typically, attention span is about eight dots (reported at 50% accuracy) (Woodworth, 1938). This span, however, depends on exposure time of the signals. Averbach (1963) found that only one item can be reported for 40 millisecond exposures with level of accuracy increasing by one item for every increase of 10 milliseconds until the span of eight items is reached. This suggests that limitations in the span of attention depend upon the limits of memory. What are the limits of man's ability to retain information presented a single time? About 8 items is the average memory span (based on traditional memory span experiments employing college students). With practice this can be increased to about twelve items. Memory span also varies with the type of item the individual has to report (Fitts and Posner, 1967).

The spatial-temporal aspects of information processing is also of importance since in many instances man must respond to events that are spaced in the time dimension. Hick's (1952) findings suggest the general conclusion that response time varies as a logarithmic function of the number of stimulus events but the rate of gain of information is constant. When the man is required to respond at a faster rate or at the same rate but to a greater number of stimuli, performance accuracy will decrease proportionately so that the same amount of information is transmitted.

Human performance is limited under conditions of excessive temporal input demands (e.g., multi-channel events, rapid sequences of events, overlapping signals). The researches by Conrad and by Mackworth (summarized by Howell and Briggs, 1959) indicate that perceptual failures accompanying increases in speed and load are related to: a) the intervals separating stimuli from the immediately following stimuli as well as from the preceding responses, b) the bunching of short intersignal intervals, c) the disorder of responding associated with short intersignal intervals, and d) the stress associated with increases in task demands. Performance also suffers proportionally as the degree of overlap among signals is increased or the number of short intervals separating them from each other or from other responses is increased.

Based on the literature, Howell and Briggs (1959) have provided the following recommendations.

- Displays utilizing single physical dimensions should not present more than 8 or 10 alternative signals for absolute identification by the operator. In general, adding new dimensions is more satisfactory than adding steps along a single dimension, although the contribution of each new dimension is likely to decrease as the number of compounded dimensions is increased. The greater the number of alternative stimuli to which the operator must respond, and the greater his uncertainty regarding which of the alternatives will appear at a given time, the greater will be the latency of his response. If forced to operate at a constant speed, accuracy will suffer as stimulus uncertainty is increased. The specific capacity values for human information processing cannot be given directly since a number of additional variables enter into such a determination, including the adequacy of the coding scheme, the compatibility of the stimulus and response, the severity of distractions (e.g., noise), the degree of time-sharing requirements, and the number of responses required.

- Techniques for improving information-handling capabilities include: a) the addition of redundancy to the signals (particularly when the situation is "noisy" or the signals are not easily distinguishable), b) the weighting of signals according to importance and relative probability of occurrence (informing the operator of these weights to reduce his uncertainty), c) the physical arrangement of signals to take advantage of the above weightings as well as any sequencing effects which might reduce the operator's uncertainty regarding signal occurrence, d) the utilization of S-R compatibility stereotypes in selecting controls for specific displays, e) the use of the auditory modality when considerable time-sharing is involved.

- In tasks which demand the precise timing of responses to continuous inputs, considerable attention should be paid to the sequencing of events. The closer a signal is to a response, the more apt this signal is to be missed. Hence, raising signal speed will cause an increase in frequency of missed signals, although the temporal accuracy of each response will be minimally affected. Raising the speed will also tend to bring about a predominance of late responses. Increasing the number of displays over which signals are presented is likely to create a stressful situation similar in effect to that resulting from an overall speed increase. It has been suggested that optimal performance can be achieved by displaying only those signals which are to be responded to currently and in the near future (the so-called "now" type of display). Other suggestions include, allowing the operator to regulate overall pace of inputs, or where this is not possible, setting speed approximately to a normal distribution of interstimulus intervals; and reducing the number of extremely short interstimulus intervals.

When the operator must choose an information source from among a group of such sources, his decision is based heavily on subjective probability estimates and priority values. Howell and Briggs (1959) suggest that the operator usually responds to the highest combination of probability and payoff values in preference to either higher probability or payoff values alone, and will choose high probability values when the combination is equated. (Other task and organismic variables may also, however, enter into the decision.)

In decision-making situations where the quality of the decision takes priority over speed, models have been proposed based on game theory and statistical decision theory which form bases for the formulation of rational decisions under uncertainty (Edwards, 1954). Pew (1965) has written:

> "In a game against nature the possible states of nature (indicated by index i; $i = 1, 2, \ldots, n$) and the available courses of action (indicated by index j; $j = 1, 2, \ldots, m$) form a two-dimensional decision matrix defining the outcome structure of the game. To each cell of this matrix is assigned a value V_{ij}, the amount to be gained or lost, associated with each outcome. A further relevant variable is the probability P_i associated with each of the alternative states of nature. This probability reflects the likelihood that any particular state is, in fact, the true state at the time the

> decision is to be made. It is possible to propose many different criteria of good decisions based on the information given. Not all will lead to the same decision. Maximizing expected value (EV) is one criterion which is appropriate to many situations. Under this criterion the operator selects the action (j) so as to maximize over m the function
>
> $$EV = \sum_{i=1}^{n} V_{ij}P_i$$
>
> thus taking into account both the probability of each possible state and the values associated with all possible outcomes." (pg. 31-13)

This appears to be a good guide to follow in making rational decisions under uncertainty. It is, however, not descriptive of what man actually does. The logic of maximizing expected value is sound, but rarely are objective data about P_i or V_{ij} available. Since each decision situation is unique and we see only a single outcome revealed, it is often difficult to obtain the classical kind of relative-frequency assessment of P_i. Similarly, only in certain limited circumstances can a well-defined value be placed on an outcome. Research has shown that man deviates significantly from expected value predictions, and occasionally fails to satisfy even the simplest axioms of rational behavior. To circumvent the limitations of expected-value maximization as a description of actual decision-making behavior, the objective-probability should be replaced with a perceived probability and the actual value replaced with the perceived equivalent of value, utility. "Subjective probability and utility usually are assumed to bear a monotonic relation to their respective objective quantities. The resultant theory is called subjectively expected utility maximization (SEU), and it has been shown to be capable of describing decision-making behavior over a wide range of conditions. Its limitation lies in the looseness of the description inherent in a model with two parameters which are only indirectly measurable and difficult to infer independently. The SEU model has been applied mainly to static decision-making tasks, the cases in which all the evidence that is to be available arrives at once and a single decision is required. In contrast with this type of task is the more general case of dynamic decision making in which the operator processes information as it arrives and makes a sequence of one or more decisions which may or may not be interdependent. While this description is more typical of the real world, it is also more difficult to analyze. The dynamic-programing methods are relevant here, as is Bayesian statistical inference." (Pew, 1965; pg. 31-14.)

3.4.2.3 Distortions in Input Information. The trainee must often, as a matter of course, respond to distortions in the input information since these occur in the operational system. Since various forms of distortion tend to degrade the information processing capabilities, the relationships are of importance to design particularly for establishing levels of task realism and for deliberately graduating the level of task difficulty in simulation to achieve defined training objectives. Several forms of distortion relevant to human factors design are described here addressed primarily to visual display requirements.

3.4.2.3.1 The Influence of Noise. A number of investigations have consistently revealed that signal identification capability in static displays is degraded as noise levels are increased. In these instances the noise serves to increase task difficulty both in terms of clutter (signal and noise) and ambiguity in signal identification, and, for dynamic displays, in terms of relevant/irrelevant signals. In form discrimination experiments concerned with sorting metric figures (Rappaport, 1957), the effects of redundancy on the recognition of visual patterns in visual noise were examined. When noise elements were present, rate of sorting was degraded. However, when redundancy was added under the background noise condition, rapid discrimination was facilitated. There was also the suggestion that redundancy may be detrimental when introduced in too great amounts or in an ineffective way.

French (1954) studied the effect of randomly scattered points of light (visual noise) on the recognition of random dot patterns of varying complexity (pattern dots varied from two to nine; noise dots from one to eight). The subject was required to identify each test pattern within 5 seconds after presentation using a noise-free figure as the sample. Increasing the complexity of the target pattern (i.e., increasing the number of elements) improved recognition performance progressively. However, increasing the complexity of the visual noise produced a progressive decrement in target recognition. Increasing the elements in the target pattern beyond eight does not appear to influence further improvement in performance. In general, recognition performance improved as the ratio of number of target dots to noise dots increased up to a target-to-noise ratio of 3:1.

For compensatory tracking tasks, the addition of increasing amounts of noise to the input signal reduces performance significantly (a roughly linear function of RMS error relative to noise level). Studies by Kahn and Mazina (1957) required the trainee to track a coherent course signal to which was added the noise signal. Error was greater at all noise levels as the input signal was raised from 0.9 to 4.5 cpm. Howell and Briggs (1959b) found similar increases in tracking error resulting from increases in visual noise. Noise was added selectively to the input, the feedback, the input plus feedback or the error signals on the compensatory tracking display. The trainee was not able to filter out the noise since his error, when he was forced to filter the noise, was greater than that possibly achieved by tracking perfectly the noise signal.

It is interesting to note that in a transfer of training study utilizing a compensating tracking task simulating an F-86 aircraft E series fire control system (Briggs, Fitts, and Bahrick, 1957), visual noise degraded performance at all stages of learning. On the transfer trials, however, all groups were found to be of comparable proficiency. Several training procedures did not differentially affect tracking performance under varied conditions of noise. The authors concluded that visual noise depresses performance levels but has little net effect upon learning in this skill task.

Howell and Briggs (1959) provide the following summary based on laboratory researches.

- Noise, or unwanted random signals, in the input has been found to degrade performance seriously on a number of different types of perceptual task: detection of auditory signals, detection of visual signals, recognition of matrix dot patterns or similar nonsense forms, and tracking under both compensatory and pursuit modes.

- The variable of prime importance in the consideration of noise distortion is the ratio of signal-to-noise magnitude. Hence, failing to lower the noise level, the same result can be achieved by raising the signal level. In auditory displays this is a matter of amplifying signal energy as in the case of certain visual displays, e.g., intensity of radar returns and amplitude of signal excursions in a tracking task. In other visual situations the analogous operation is increasing the number of signal elements. In dot matrices, the signal-to-noise ratio or the number of dots defining the pattern relative to the number of random or "noise" dots appears to be the most significant variable. For a given number of signal dots, errors increase as a negatively accelerated function of noise. Similar findings obtain with respect to metric figures in that figure redundancy is effective in combating noise decrements.

- Adding redundancy in auditory as well as visual displays is a particularly effective means of combating noise effects. When it is possible to reduce distortion on some, but not all, display channels, it appears that the greatest benefit will result from optimizing those displaying input information. The distortion of feedback information is less serious owing to its inherent redundancy: proprioceptive as well as visual cues are available in most control tasks.

- For dynamic displays, increasing the amount of noise appearing on a tracking display brings about a nearly linear decrease in accuracy of performance (at least for relatively low noise levels). In this situation noise appears as a random perturbation of the coherent movement patterns described by the display elements. Introduction of noise selectively to the various display elements (i.e., input signal, feedback signal, both input and feedback signals, and the error signal in a compensatory display) reveals that performance is seriously affected only when input information is involved. It is presumed that when visual feedback information is disrupted, the operator places more reliance on proprioceptive feedback cues.

3.4.2.3.2 Signal Intermittency. Signal or display intermittance is a design issue in situations involving discretely sampled information such as with radar displays or involving time sharing in multi-display contexts. The general finding from the literature is that performance decreases as a function of the display intermittence period (Howell and Briggs, 1959). In multi-display situations, man sets up a scanning pattern and his performance is slowed due to attention switching and eye movement times. Broadbent (1955) found attention switching time to be on the order of 0.2 seconds.

Intermittency degrades tracking performance; as the percent time of viewing the signal decreases, performance decreases in an approximately linear fashion (Battig, et al, 1955). However, with simple inputs and no requirement for quick and precise response, the harmful effects are minimized. The effect of intermittency is modified by input complexity, display brightness, and the frequency of intermittence. Flash duration in an intermittent signal usually affects target brightness, with brightness lessening as flash durations decrease. For example, a brightness of +10 ml yields better performance than a brightness of 0.05 ml which in turn results in better performance than a brightness of 0.005 ml (Voss, 1955).

A study by Poulton (1957) provided for selective intermittency in the target signal, feedback, and target and feedback combined for a pursuit tracking display. On-time was 0.4 second duration and off-time intervals varied from 0.2 to 4.7 seconds. In all instances performance was degraded (mean error score) as the duration of off-periods lengthened. Feedback intermittence was least disruptive of performance. Several means for reducing the harmful effects (especially during early stages of training) of intermittency have been summarized by Ely, Bowen and Orlansky (1957).

- Anticipatory information should be provided by the display.
- Brightness level of the display should be kept high.
- In multi-display formats requiring the development of a scanning pattern by the operator, displays should be designed and arranged to minimize viewing time and attention-shift time.
- The duration of each intermittent signal should be as long as possible and the rate of presentation should be as fast as possible.
- Aiding or quickening should be used, when applicable.

In general, the function obtained between proficiency measures and the frequency of signal glimpses is negatively accelerated. This relationship has been observed for intermittent feedback as well as for intermittent input information. The feedback case is considerably less detrimental to performance than is the input case and this suggests further evidence that man is able to substitute proprioceptive for visual feedback information when the latter is degraded in some way (Howell and Briggs, 1959).

3.4.2.3.3 Time Lags. Lags are an integral part of many control tasks and hence must be considered in specifying display and control requirements. The distinction has been made between display and control lags, the former occurring between the output and the display and the latter between the control and the output. Garvey, Sweeney and Birmingham (1958) employing a compensatory tracking task found that performance error increased linearly as display lag increased to 0.75 seconds. Under control lag conditions, error leveled off after 0.20 seconds.

Lags can be characterized in terms of where they appear in the system. The three major types are transmission, exponential and sigmoid lags. Transmission lags, even when extremely small (e.g., 0.06 seconds), tend to degrade performance with compensatory displays. For transmission lags in a compensatory task, Warrick (1949) found that performance decrement is a linear function of lag from 0 to 320 milliseconds;

for exponential lags, Warrick (1955) obtained an approximately linear function between time-off-target and lags from 0 to 1000 milliseconds. Exponential and sigmoid lags can either improve or degrade performance depending on their interactions with other aspects of machine dynamics (Ely, Bowen and Orlansky, 1957). For example, Rockway (1954) found that when gain is optimally set, an exponential lag added between control output and machine output will degrade performance. If, however, the gain is set too high (causing continual overshooting), the lag will serve to reduce output amplitude and thus improve performance.

Howell and Briggs (1959) hold that the distortions created by system lags can be averted in many complex systems by displaying to the operator feedback information not only of system output but also of its derivatives. This technique, known as "quickening," can reduce the effects of such delays on performance and can, in addition, greatly simplify the operator's task (see 3.4.3.2).

In summary, distortions of input information must be reckoned with in design, not only in terms of the negative features which in certain instances must be minimized, but in terms of the positive values for training. For example, noise and intermittency distortions are of some value in providing a means for the development of a training strategy and must be considered as a design option for certain task situations. The prominent feature is that task complexity can be increased via these means and graduated levels of task difficulty may be specified precisely.

3.4.2.4 Stimulus-Response Compatibility. The human does not have a fixed limit for the rate at which information is transmitted. Processing rates vary as a function of the matching of stimulus and response coding and of different amounts of learning. Fitts (1958) has summarized a number of studies in which stimulus-response compatibility is a significant task characteristic, i.e., certain stimulus codes are responded to more accurately and more rapidly with certain response cues.

A number of studies have varied the assignment of responses to stimuli. Morin and Grant (1955) employed reaction time as a measure for three different S-R codes; Fitts and Deininger (1954) also employed reaction time as a measure for various stimulus codes and for several different ways of assigning stimuli to responses; Fitts and Seeger (1953) used measures of reaction times, errors and information-transmission indices to compare nine different S-R ensembles; Garvey and Knowles (1954) compared performance for six S-R ensembles; Garvey and Mitnick (1955) examined the spatial anchoring effects important in S-R compatibility. The above studies, representative of the literature, have yielded the following:

- Performance depends both upon the stimulus and the response codes. A particular response code may yield greater performance with one stimulus code than with another.

- Factors contributing to the stimulus-response compatibility effect are population stereotypes, spatial anchoring effects, and the relative probability of occurrence of specific stimuli.

- Performance, measured by speed and accuracy is usually in agreement with the compatibility of the S-R code in terms of population stereotypes.

- The effects of compatibility will continue over long periods of practice.

- When an ordered set of stimuli is used, reversal of stimuli yields better performance than does a random assignment of stimuli to responses. An incompatible S-R code while slower than a compatible one seems to be effective provided some well-learned rule is supplied.

- The source of compatibility effects appear to reside in previous learning and in genetic bases.

Fitts (1954) has stated that because all motor responses involve a distribution of force in time and space, the spatial characteristics of the stimulus code is especially important in determining S-R compatibility where rapid motor responses are required. Compatibility effects are interpreted in terms of probability learning, the adequacy of man's expectancies relative to the set of alternatives present in a particular task situation, and the degree of re-encoding of information required in the S-R sequence.

S-R compatibility has also been examined in tracking tasks. Howell and Briggs (1959) have summarized the research concerned with such issues as control movements relative to displayed stimulus positions, the effects of display variables in complex tracking tasks and the congruence of S-R sets in pictorial reference indicators. For example, fly-from or inside-out displays are superior to fly-to or outside-in displays in the pictorial representation of position. For circular display-control configurations, similar display and control movement is generally superior to reversed rotation, although with the null position at 6 o'clock the extent of this superiority is doubtful. Regarding the optimum null position, the 9 o'clock position has been found to be particularly advantageous when two separate compensatory displays are used and these are aligned horizontally. When two such displays are aligned vertically, however, the 12 o'clock position becomes superior. The 12 o'clock position also appears to be superior when one display is used. These writers make the following recommendations for design:

- Control-display combinations should always be selected to take advantage of S-R compatibility effects. Many such preferred relationships have already been determined. Very generally, spatial correspondence of multiple stimulus and response elements (e.g., position of lights and response buttons in a matrix) appears to offer a high degree of compatibility. In the same manner, directional correspondence of moving elements (e.g., a left-moving cursor on a CRT and the leftward movement of a control column) are highly compatible. Verbal responses have also been found to be more compatible than manual responses (i.e., key pressing) in relation to alphanumeric stimuli. For unique situations, data should be collected to determine the stereotypes of the potential operator population with regard to preferred display-control relationships. These expressed preferences should then be tested using models of the alternative combinations. Generally speaking, the differences in preference and performance are marked, so that relatively few data would be required.

- Several additional principles may be found useful in optimizing compatibility effects. When large groups of stimuli and accompanying response elements are involved (as is the case in matrices, columns, etc.), spatial reference lines can be used to "break up" the groups and thereby improve performance. In addition, assigning high-probability events to spatial anchor points (i.e., edges, tops, bottoms, etc.) may improve overall transmission efficiency.

3.4.2.5 Vigilance. How man performs in situations characterized by infrequent event occurrence over time (weak, relatively rare signals) is also of interest to design, particularly when he functions as a monitor in various system situations. Prominent among these minimum input situations for training design are the sonar and radar vigils, monitoring of system states (in and out-of-tolerance) under various modes of operation (e.g., semi-automatic), and monitoring multi-display situations of varying complexities and of varying information feedback capabilities.

A substantial body of literature exists on vigilance behavior and performance under low frequency input conditions and a considerable array of research findings have been assembled for a variety of task situations and methods. It is suggested that the reader consult the reports prepared by Buckner and McGrath (1963), Human Factors Research (1968), Jerison and Pickett (1963), Swets and Kristofferson (1970), Broadbent (1958) and Frankmann and Adams (1962) for a sampling of the issues, problems and findings. Theory development accounting for vigilance and monitoring behavior has developed similarly. Prominent among these are the Filter Theory (Broadbent, 1958), Arousal Theory (Scott, 1957), Reinforcement Theory (Jerison and Pickett, 1963), and Expectancy Hypothesis (Deese, 1955), as well as other related positions or hypotheses.

Our purpose is to extract from this significant body of literature, concepts and information pertinent to the design of displays for training systems.

The research literature on human vigilance indicates a heavy involvement in studies concerned with man's ability to detect signals presented in simple displays. An example of this is suggested in Figure 38 which illustrates the commonly achieved decrement function in human vigilance. As an oversimplification, the classic finding is a performance decrement showing a monotonic decline in signal detection as a function of length of vigil.

The major theories would predict the classical performance decrement under prolonged vigil conditions (Buckner and McGrath, 1963). For example, Filter Theory holds that because of man's limited perceptual capacity, a selective operation is performed on all inputs to the system. During the monitoring task, the man will select irrelevant competing stimuli with increasing frequency over time. The result is a decline in the percentage of signals detected. For Arousal Theory, the prediction of the classical vigilance decrement is based on the assumption that long-term monotonous stimulus conditions will lead to a lowering of cortical arousal and thus to less efficient responding.

However, the findings are mixed regarding a sensitivity decrement for all kinds of vigilance tasks. Some yield a reduced sensitivity over time; others do not suffer with the passage of time. A prominent variable to account for this is the type of display employed (Swets and Kristofferson, 1970).

Probability of detection is affected also by temporal signal uncertainty. An example of laboratory results relating signal rate to probability of detection is presented in Figure 39. The differences among the curves may also be due to the type of display employed and variations in procedure.

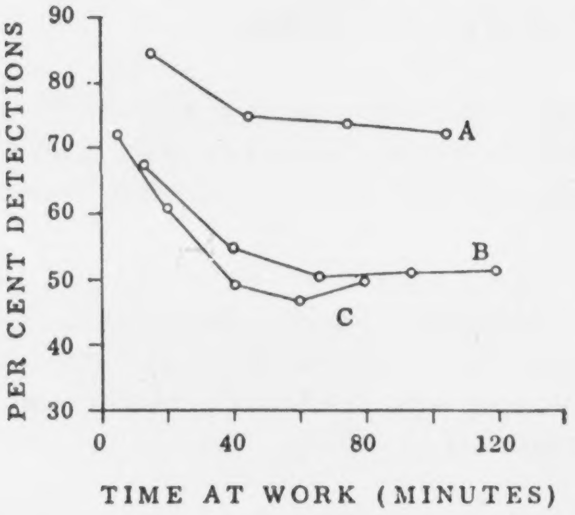


Figure 38. Three performance curves from different laboratories illustrating the decrement function in human vigilance. A-Mackworth (1950); B-Jerison and Wallis (1957); C-Jenkins (1953). All curves based on signal rates of about 30/hr and display with no spatial uncertainty. (from Jerison and Pickett, 1963)

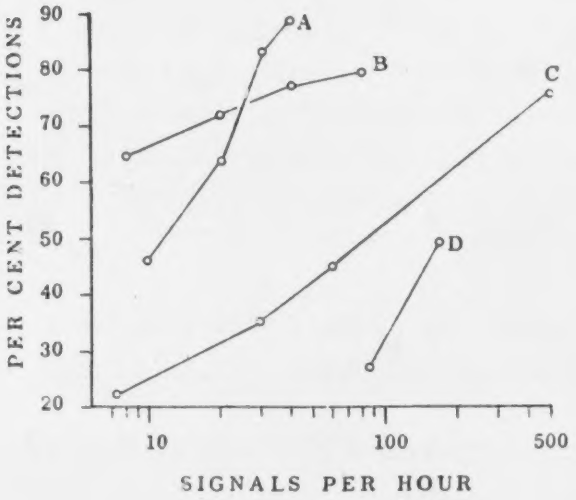


Figure 39. Percent signals detected as a function of log signal frequency. A-Deese and Ormond (1953); B-Kappauf and Powe (1959); C-Jenkins (1953, 1958); D-Jerison (1959). (The log scale, used for convenience in graphing, has no theoretical significance at this time.) (from Jerison and Pickett, 1963)

The vigilance decrement, characteristically found in low signal frequency, simple monitoring tasks does not seem to occur in the monitoring of complex visual tasks (Adams and Boulter, 1964), particularly as the level of display complexity (stimulus density) increases.

The consensus, however, is that the probability of signal detection in monitoring low-frequency events will usually show a decrement over work time, although the decrement may not occur if the task involves spatial as well as temporal uncertainty of the signal (Jerison and Pickett, 1963). Additional relevant variables include: signal characteristics (frequency, regularity, size, intensity and spatial distribution); the level of extraneous visual and auditory noise; the schedule of reinforcement for observing responses (Holland, 1958); and the design of the displays (Swets and Kristofferson, 1970).

A number of techniques may be used to increase the likelihood that signals will be detected in low-frequency event situations. These include the following:

- Increase the number of targets that must be detected. The probability of detection (in terms of wanted signals) increases according to the logarithm of the number of signals per hour.
- Insert occasional false or "dummy" targets.
- Provide information about when and where a signal is likely to occur (position on the display). A reduction in unpredictability in space is desired, e.g., monitoring will be improved when several spatially separate signal sources are combined in a centrally placed display.
- Increase signal probability (increase signals-per-unit-time by using a longer unit of time).
- Introduce unrelated stimuli at various intervals, e.g., alerting signals).
- Intensify or enlarge the signals. Display size should be large enough to be legible but not to interfere with easy visual search. Thus, a display that subtends ±5 degrees is better than larger versions for the same visual material.
- Increase the absolute detectability of the signal (increasing its duration improves signal to noise ratio).

- Provide augmented feedback information preferably via training equipment.

- Add redundancy to the signals (e.g., auditory signals).

- Introduce artificial conditions in the displayed situation. The introduction of successive events at regular time intervals (e.g., a signal repeated every 3-5 seconds until detected) will assure sustained vigilance under circumstances that otherwise would yield a falling off in performance.

- Enhance neglected portions of a display or of the total displays by enhancing the stimulus (e.g., differential brightening) or by intensification of reference markers on the display in order to distribute the man's attention.

- Eye movements are particularly important in monitoring PPI screens. For example, the presence of a scanning radial line of sight has been shown to yield disproportionately great eye fixations in a ring at the half-radius region of the circular screen. Thus, detections are most likely to occur at a position half-way out from the center of a circular display (N. Mackworth, 1960).

It should be noted that the above recommendations are based mostly on laboratory data of which there is a limited amount of basic data. In essence, the results obtained from the vigilance researches support the need for augmenting trainee compartment displays to enhance training effectiveness, specifically the need for prompts, cues, knowledge of results to be provided in equipment as well as deliberate departures from realism with respect to the operational world. These issues will be covered subsequently in Chapter 3.7 of this Section.

3.4.3 Design Techniques for Enhancing Displays for Training. A number of techniques are available for the design of displays which emphasize instructional efficiency. These may be grouped under the rubric of stimulus coding and are concerned with augmenting the identifiable coding dimensions by which information can best be displayed to the man to achieve training objectives as a function of level of learning. The techniques provide for the enhancing of signals to insure detection and identification of signals in cluttered displays and also to insure effective monitoring of signals in complex displays so long as the signal is of concern in an exercise (e.g., coding of targets to indicate imminent violation of minimum lateral separation in an air traffic control display).

The principle underlying this usage is simple--provide guidance to essentially delimit the frequency and severity of incorrect responses in performance by emphasizing relative aspects of training and limiting the exploration time in performance. This takes on two aspects: 1) the signals/targets must be generated and coded in such ways as to insure the achievement of the training objectives for the training system; 2) where stimulus supports are desired, these should be organized in ways compatible with achieving the desired training objectives. The effectiveness of this guidance depends on the amount given and the point in training at which it is introduced. It is most efficient at the outset of learning (initial training) when offered in discreet doses. When given in large amounts at inopportune times, it may actually interfere with learning. Thus, proper use dictates that display enhancement must not continue to the point where the trainee becomes overdependent on outside aid, for skill acquisition requires performance without assistance. Response cues must be eventually withdrawn so that the trainee responds to the stimulus desired in terminal performance. (On cue withdrawal or stimulus fading, see Skinner, 1960.)

3.4.3.1 Information Coding. Information may be presented in a variety of ways to the performer. Some of these ways are more effective than others in enhancing speed and accuracy of human performance. Thus, the form of the information presentation and how it is encoded is of great relevance to design for training.

Considerable research has been accomplished on coding variables, specifically, on such commonly employed means as: color, shape, size, intensity, orientation, alpha-numerics, line length, pulsing signals and the use of target traces to indicate previous position. The literature is sizeable and the reader is urged to consult the many available human engineering compendiums for specific information (for example, two such sources are the reports by Fitts (1954), and by Baker and Grether (1954)). Some generalized findings from the literature are outlined below.

- About 10-12 different colors is the maximum that can be consistently identified. However, in terms of current color generation methods, 7 should be considered a practical limit. In fact, a limit of 4 is desirable to alleviate color registration problems.

- A maximum of four size levels is desirable from the standpoint of clutter and from limitations in character generation.

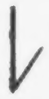
- Shape coding is constrained by the ability to generate the characters.

- Intensity is not a desirable dimension since average display density may be too close to minimum allowable to permit a dimmer symbol. Brightest intensity may be used as a means of attention-getting.

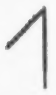
- Orientation of a vector is useful for indicating heading, usually a maximum of eight; vector length is useful for representing gross speed range indication; time-to-go may be coded as a circular vector.

- Alpha-numerics are commonly used and offer unlimited possibilities. They are usually assigned meanings that can be easily interpreted.

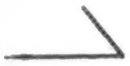
A meaningful example of the use of alpha-numerics as a display variable is shown in research conducted on Air Traffic Control.[1] A display variable found to have a pronounced effect on system efficiency in terminal area air traffic control operations is the coding of aircraft blips (Schipper, et al, 1957). A visual code was developed for the primary display as a means of providing controllers with knowledge of the identity of incoming aircraft. It was in the form of an alpha-numeric clock-code. The longer hand of the clock code is read as Alpha, Bravo, Charlie or Delta; the shorter hand is read as the corresponding clock numeral. Thus,



Alpha 1



Charlie 8



Delta 11

The code finally selected resulted from research on coding for efficient handling of information. The procedure included scaling the stimulus by means of absolute information transmitted and determining the rate at which this information was transmitted (Muller, et al, 1955). The effect of the use of this identity code on accumulated delay in aircraft landing is shown in Figure 40. As the rate of entry (number of aircraft entering the terminal area per unit of time) is increased beyond some point, measures of system efficiency declined uniformly. The average control time showed a marked upward trend as the average time separation between successive entries decreased beyond one aircraft every 90 seconds for the condition of no identity, and as it decreased beyond one entry every 75 seconds for the condition in which identity was given. The number of conflicts also

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[1] An extensive research program was conducted at the Laboratory of Aviation Psychology, Ohio State University by Paul M. Fitts. The work, begun in 1950, was supported by the National Research Council with funds provided by the Air Navigation Development Board. After 1952, the research program was supported by the Wright Air Development Center, Wright-Patterson AFB, Ohio (Contracts AF 33(616)-43 and AF 33(616)-361

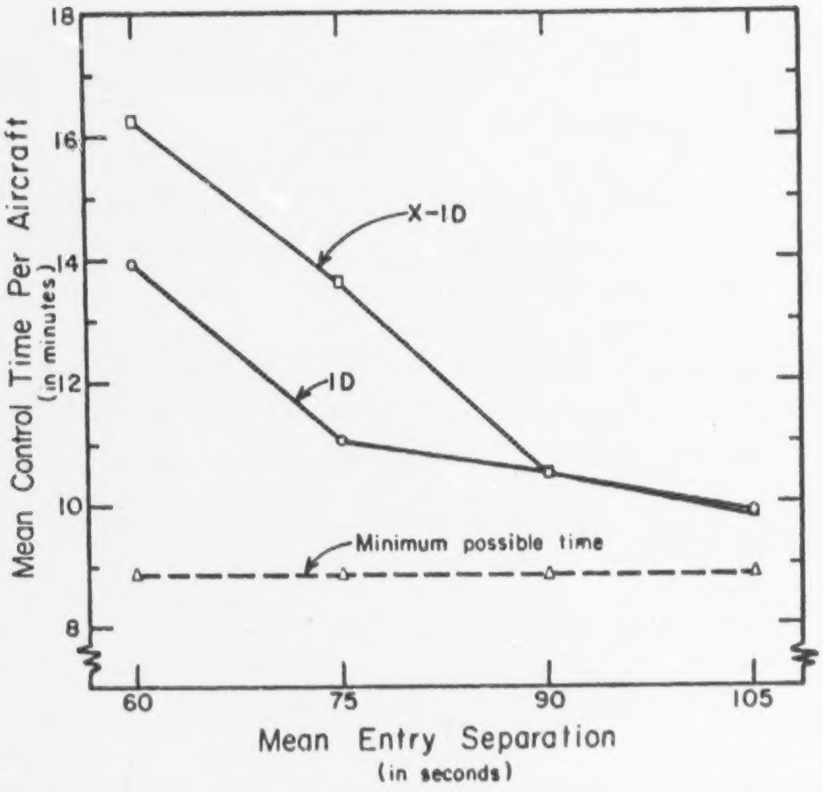

Figure 40. System Performance at Four Entry Rates Under Identity and No-Identity Conditions. ID Indicates Identity; X-ID, No Identity. (from Schipper, Kraft, Smode and Fitts, 1957.)

increased as a function of increased entry rate. These data are for a system in which a single controller was required to handle all aircraft, and entries deviated randomly around the mean temporal separation and appeared anywhere within a 90-degree sector of the periphery. All aircraft were inbound, and had to be moved through a 50-mile zone in order to reach the GCA gate.

Another technique of coding may be described as target enhancement, which involves modification of one or more of the stimulus dimensions defining the object(s) of interest in the display. This method is particularly amenable to computer generated synthetic displays, and is normally employed as a means of bringing the trainee's attention to an object (e.g., aircraft, ground target), or to an out-of-tolerance condition (e.g., minimum lateral separation, critical weapon release distance) which demands an immediate and appropriate response in the operational environment.

The most common techniques comprising this form of coding involve increasing the brightness contrast between an object and its background, changing the color of a target, increasing the size of an object, or varying any one of these dimensions on a temporal basis (e.g., flicker, undulation of object size, color flashing or displaying the previous "X" seconds of a moving target as a means of enhancing the ability to detect slow-moving targets). These latter techniques involving some sort of temporal variation are preferred to the other steady-state techniques mentioned above. For all practical purposes, these techniques are considered equally effective in terms of this attention-getting power and have been successfully employed in a number of applications.

Selection of a specific technique must be made in light of the display medium employed and the ease with which it can be implemented in the system. In some instances, the medium dictates the techniques that may be used within realistic cost limitations. CRT displays are, for example, more amenable to any one of these techniques than are optically projected displays.

The attention-getting power or conspicuity of "enhanced objects" in the display depend on the rate with which the signal is pulsed. The experimental literature does not suggest any one rate as being optimum, and the various optimum rates that are reported vary as a function of viewing conditions, light-dark ratio, and task loading. The consensus of these studies (e.g., Projector, 1957; Gallup and Hambacher, 1956), however, indicates that rates of 2 to 4 per second define the optimum zone over a wide range of conditions. It is recommended that these rates be employed when this form of coding is considered desirable.

3.4.3.2 Prediction of Input Information. Information acquisition and processing can be simplified as a result of the design of the information interface between the man and the system. This concerns the technique of providing predictive information to the operator. Proficiency in a number of tasks (e.g., docking maneuvers, carrier landing, maintaining lateral and vertical separation of aircraft in air traffic control, etc.) depends on man's ability to predict the immediate future path of a target or of own vehicle in relation to a target.

Howell and Briggs (1959) in a review of studies concerned with man's ability to predict motion, to predict intersect or collision courses, and to predict future position of moving objects, concluded the following:

- Man relies primarily on position, magnitude and direction characteristics of input signals in extrapolating the course of a moving target. Man should not be required to estimate the acceleration characteristics or higher derivatives of input signals.

- The accuracy of linear extrapolation is generally found to decrease with distance extrapolated, hence operators should be provided with objective methods for extrapolating long distances. What constitutes a long distance is dependent, of course, upon the size of the display, the tolerable error, the speed of the target, and a number of other variables. At a normal reading distance, however, a 1-inch extrapolation will result in an average of 0.2-inch error; a 6-inch extrapolation in an average of 1.4-inch error. In extrapolating curved courses such as the point at which an aircraft appearing on a PPI will "roll out" of a turn, judgments become poorer as the radius of arc is increased (particularly for sharp turn angles). For a radius of arc of 3.03 mm., for example, variable error has been found to be 1.50 mm. and constant error to be 0.97 mm; for a radius of 24.24 mm., variable error approaches 4.69 mm. and constant error +7.88.

- The extent to which speed of target movement influences extrapolation and collision judgments is not clear. In some cases, raising speed appears to degrade performance, and in others it has little or no effect. It is fairly certain, however, that in projecting the course of targets moving at *unequal* speeds greater error results than for targets moving at equal speeds. Therefore, any objective means of improving projections of targets moving at unequal speeds can be expected to aid performance and should, if possible, be adopted.

- Several other variables have importance for specific types of display situations. Trails of constant brightness, for example, should be used to denote speed for targets approaching each other at an oblique angle; fading trails are superior when the approach forms an acute angle. For judgments of the future range of moving targets, the linear PPI display is superior to the exponential PPI or B-scan display. Bearing estimations are particularly poor on the exponential PPI display.

- It does not appear to be necessary to provide man with an abundance of past course information in many types of perceptual prediction or extrapolation tasks. In extrapolation, for example, judgments based on the minimum number of points necessary to define a course are as good as judgments based on a row of closely arranged points. In tracking tasks, predictions of future position (and therefore error scores) are relatively unaffected by the display of past course information. Attention should, therefore, be directed toward providing the operator with accurate and readily visible recent information rather than an extensive amount of past information. In tracking it is particularly important that the operator have some knowledge of the overall statistical properties of the input to aid in his prediction of the future.

Displays have been developed which obviate the requirement for learning the dynamics of complex control systems. One of these display aids is the "Quickened" display, a modification of a closed-loop manual control system which changes the task performed from complex control system tracking to the tracking of a positional control system without lag. The display shows the operator how to make control movements proportional to the size of the displayed error. It informs him as to what responses should be made to bring about appropriate system outputs. This greatly reduces the output error of the system (Birmingham and Taylor, 1954).

A "predictor" display provides the operator a display of the response characteristic of the system in terms of predicted system output at some time in the future. This type of display simplifies the task by providing the operator information relative to the future of the variable being controlled. The operator is not required to integrate and extrapolate system parameters to develop a predictive model of the system (Kelley, 1960).

These types of displays should reduce the difficulty of tracking with a complex control system and should also reduce the size of the error of the control-system output.

3.4.3.3 Actual vs. Simulated Targets. Another of the issues facing the human factors specialist concerns the design decision on selecting simulated versus actual targets for display. This selection must be based on a careful consideration of the visual tasks the trainee is expected to learn and on the conditions under which they are performed in the operational environment.

If the task involves detection, recognition, and identification of near threshold targets in complex or "high noise" environments, then actual targets are desirable. However, if the task involves tracking or maneuvering relative to the target, then actual targets contribute little to development of this skill. In this case, simulated targets would serve the training objective quite satisfactorily. It should be emphasized, however, that tracking ability is sometimes heavily influenced by target fading and the ability of the observer to reaquire the target under adverse environmental conditions. Under these circumstances, tracking performance depends quite heavily on the ability of the observer to accomplish the basic visual processes of detection, recognition, and identification, even though they may occur almost instantaneously. For this reason, actual targets must sometimes be employed in simulator displays which are used exclusively for developing tracking skill.

Mackie and Harabedian (1964) recommend the following concerning simulated vs. actual recorded sonar target signals.

- For training in target detection, the use of variable signals in a background of noise appears mandatory. It is probable that highly realistic synthetic signals represent a better choice than recorded target signals for this purpose because of the much greater stimulus and problem control that such signals afford.

- For training in target tracking, the use of less realistic signals can be tolerated. However, the tracking function will be seriously interfered with whenever variations in signal intensity or excessive masking by noise produce temporary loss of contact. The moment that tracking responses become dependent upon detection responses, as is frequently the case in actual operations, the signal realism requirements for tracking must approach those recommended for target detection. While actual target recordings could be used for tracking training, synthetic signals are preferred.

- For training in active classification, actual target recording is superior. However, the use of highly realistic synthetic signals appears to be entirely feasible. The inclusion of variability in all displayed signal parameters is essential for effective training in active classification. The addition of background (reverberation) noise is also desirable. And, obviously, all major information parameters used in classification must be represented in the synthetic signals.

- For training in passive classification, recordings of actual target signals are superior to synthetic signals but synthetic signals are feasible. The inclusion of variability in the displayed signal parameters also is of importance in developing effective synthetic signals for passive classification. The addition of much background noise is of questionable value, however, because of the extreme subtlety of some of the classification clues.

3.4.4 Research Issues. A number of research issues important to training system design concerns the manner in which man copes with and utilizes the displayed information in the signal environment. Perhaps the most pervasive issue that requires resolution centers on how man copes with and learns to discriminate signals in a high density signal environment. Evidence indicates that man extracts only large elements from dynamic electronic displays and ignores other features; there is also evidence that man develops a set for what he is looking for and the display confirms his expectation. It is desirable to establish what elements man requires and uses in complex high-density displays. For example, if one can establish the elements the man requires in a specific display situation, is it reasonable to simulate only these and "paint" in the background? How does man utilize chronologically a scope display as a function of task requirements (e.g., land mass display, terrain avoidance or following, etc.); what does he attend to in target recognition, in target identification? Similarly, in multi-display contexts, how is mode selection and information integration accomplished to determine what he has developing at any given time? A pertinent design issue, for example, is do you present all the information involved in a situation or do you simplify the presentation? The importance of cueing requirements is implied but not necessarily at the amplitude and frequency found in the operational environment. Similarly, the issue of pattern recognition in clutter is of concern, i.e., the decision-making process involving a translation or mapping from a large set of stimuli or arrays to a much smaller set of events or names. Thus, the complicated issue of display interpretation is of some consequence for training design. What is needed is a system of design data on how man discriminates among much data presented simultaneously or in rapid sequence for major classes of task situations, and how he combines and utilizes information from multi-display sources dissimilar in format and content.

Another issue of interest to design is the extent of display degradation possible without performance degradation, e.g., how much reduction in tolerances is permissible as a function of training purpose? Of concern here is the issue of abstract vs. concrete representation of the signal environment and how man utilizes the information. For example, does the display of abstract figures and events on a land mass display (e.g., a river, a cluster of artifacts, etc.), instead of specific, concrete entities (e.g., a named river, a named shoreline, etc.), or does substituting a mosaic which simulates a PPI instead of higher radar resolution on the PPI, affect transfer of training differentially? The understanding of this issue has important consequences for the design of complex training displays. Allied to the above is the value of "mediation" in information display. A study by Silver, Jones and Landis (1965) indicated that with skillful radar observers, paper and pencil format displays can be presented as successfully as live simulation of the same information. For novice trainees, however, live simulation is desired with an emphasis on the relationships between stimuli rather than on single stimulus variables.

Also desirable is the development of a data base for simulator design on the number of signals/targets that the man can react to and process effectively (i.e., displayed simultaneously or in fast sequence) for various classes of tasks and display characteristics, and for target characteristics (e.g., maneuverability, speed, patterning, etc.). It is not clear, for example, where the performance breakdown points are as to the number of targets that a man can successfully handle in his span of control; it is not clear how targets are best generated in terms of man's perceptual capabilities, for various task/display requirements (e.g., dynamic and slaved target relationships, ganged signals, etc.).

3.5 MEASUREMENT SYSTEM DESIGN

This chapter presents concepts and data pertinent to the design of the performance measurement capability in training devices. Of concern are the design requirements involved in providing the means for monitoring, scoring and evaluating human performance in training systems. Emphasis is placed on automatic human performance monitoring and recording means (computer programing and scoring equipment) for providing measures and scores that can be organized, manipulated and applied to achieve the purposes of assessment. The design issues center on the data requirements for deriving measures, the selection of relevant measures, the organization of measurement data, the display of scoring information (content and technique), and the recording of measurement information.

No provision is made in this subsection to present human performance measurement technology relevant to design. The principles and practices, the pitfalls and weaknesses in defining and assessing performance is a story in itself that is well told in a congeries of documents in the open literature. We are tacitly assuming the involvement of this primary information base in decisions on selecting from the available design alternatives. In addition, a procedure involving a sequence of steps for achieving a measurement capability in a training device has been explicated in Section II of this report. Thus, we suggest that the reader consult the procedure for developing a measurement system and examine collaterally the body of literature on the available measurement technology. As an aid, a number of documents are recommended which describe in an authoritative and detailed fashion, important issues and concerns in measuring and assessing human performance. These books and reports emphasize key topical areas in measurement. No single document is sufficient as an assist in designing a measurement system. The specific studies deal with a range of considerations involved in the development of a measurement capability. A representative sampling from among many excellent sources is provided below.

General treatises on proficiency measurement

Stevens, S.S. Mathematics measurement and Psychophysics. In S.S. Stevens (Ed.), Handbook of Experimental Psychology. N.Y.: Wiley, 1951.

Glaser, R. and Klaus, D.J. Proficiency measurement: Assessing Human Performance, in R. Gagne (Ed.), Psychological Principles in Systems Development. N.Y.: Holt, Rinehart and Winston, 1963.

Churchman, C.W. and Ratoosh, P. (Eds.), Measurement: Definitions and Theories. N.Y.: John Wiley and Sons, Inc., 1959.

Obermayer, R.W. Simulation, Models and Games: Sources of Measurement, *Human Factors Journal* 6 (6), December 1964, 607-619.

Precision and Relevance in Proficiency Measurement

Thorndike, R. *Personnel Selection: Test and Measurement Techniques*, N.Y.: Wiley, 1949.

Lindquist, E.L., et al. Educational Measurement. *American Council on Education*, Washington, D.C., 1951.

Joint Committee of the APA, AERA and NCMUE. Technical Recommendations for Psychological Tests and Diagnostic Techniques. Supplement to *Psychological Bulletin*, Vol. 51, 1954.

Statistical Considerations

Guilford, J.P. *Psychometric Methods*, 2nd Edition, N.Y.: McGraw-Hill, 1954.

Guilford, J.P. *Fundamental Statistics in Psychology and Education*, N.Y.: McGraw-Hill, 1956.

Draper, N.R. and Smith, H. *Applied Regression Analysis*, N.Y.: John Wiley & Sons, Inc., 1966.

Torgerson, W.S. *Theory and Methods of Scaling*. New York: Wiley and Sons, Inc., 1958.

Gulliksen, H. Paired Comparisons and the Logic of Measurement. *Psychological Review*, Vol. 53, 1946.

Nunnally, J.C. *Psychometric Theory*. New York: McGraw-Hill, 1967.

Criteria

Obermayer, R.W. *Measurement Criteria in Man-Machine Systems Simulation.* NASA CR 257, National Aeronautics and Space Administration, Washington, D.C., July 1965.

Uhlaner, J.E. and Drucker, A.J. Criteria for Human Performance Research. *Human Factors Journal* 6 (3), June 1964, 265-278.

McCoy, W.K. Problems of Validity of Measures in Investigating Man-Machine Systems. Human Factors, 1963, 5, 373-377.

Measurement Applications in Military Training Contexts

Many studies have been conducted, sponsored by government agencies. The key agencies include the following:

- Civil Aeronautics Administration (pre-WWII)
- USAAF Aviation Psychology Program (WWII)
- USAF Human Resources Research Center (HRRC)
- USAF Personnel and Training Research Center (AFPTRC)
- Human Resources Research Office (HumRRO)
- National Aeronautics and Space Administration
- USAF Aerospace Medical Research Laboratories
- U.S. Naval Training Device Center
- Federal Aviation Agency

In addition, a number of specific applied studies has been published which deal with the development, application and review of measurement technology. These consider a variety of specific issues related to the utilization of training systems, and provide valuable background information for the design of a measurement capability in training devices. Representative studies are listed below.

Ericksen, S.C. A Review of the Literature on Methods of Measuring Pilot Proficiency. Research Bulletin, 52-25 Human Resources Research Center, Lackland AFB, Texas, 1952.

Krumm, R.L. & Farina, A.J. Effectiveness of Integrated Flight Simulator Training in Promoting B-52 Crew Coordination. AMRL-TDR 62-1, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, 1962.

Greer, G.D., Smith, W.D. and Hatfield, J.L. Improving Flight Proficiency Evaluation in Army Helicopter Pilot Training. HumRRO TR No. 77, U.S. Army Aviation Human Research Unit, Ft. Rucker, Alabama, May 1962.

Smode, A.F., Gruber, A. and Ely, J.H. The Measurement of Advanced Flight Vehicle Crew Proficiency in Synthetic Ground Environments. AMRL-TDR 62-2, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, February 1962.

Buckhout, R. and Cotterman, T.E. Considerations in the Design of Automatic Proficiency Measurement Equipment in Simulators, AMRL Memo P-40, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, June 1963.

Soliday, S.M. & Schohan, B. *A Simulator Investigation of Pilot Performance During Extended Periods of Low-Altitude, High-Speed Flight.* NASA-CR 63, National Aeronautics and Space Administration, Washington, D.C., June 1964.

Angell, D., Shearer, J. and Berliner, D. *Study of Training Performance Evaluation Techniques.* NAVTRADEVCEN 1449-1, U.S. Naval Training Device Center, Port Washington, N.Y., October 1964.

Federman, P. and Siegel, A. *Communications as a Measurable Index of Team Behavior.* NAVTRADEVCEN 1537-1, U.S. Naval Training Device Center, Port Washington, N.Y., October 1965.

Ruocco, J.N., Vitale, P.A. and Benfari, R.C. *Kinetic Cueing in Simulated Carrier Approaches.* NAVTRADEVCEN TR 1432-1, U.S. Naval Training Device Center, Port Washington, N.Y., 1965.

Brictson, C.A. *Measures of Pilot Performance: Comparative Analysis of Day and Night Carrier Recoveries.* Contract Nonr-4984(00), Office of Naval Research, Physiological Psychology Branch, Washington, D.C., June 1966.

Human Factors Journal. Assessment of Complex Operator Performance, Vol. 9, No. 4, August 1967.

Purifoy, G.R. *Instructional Methodology and Experimental Design for Evaluating Audio/Video Support to Undergraduate Pilot Training.* AFHRL TR 68-5, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, October 1968.

3.5.1 *Measurement Capabilities in Current Training Devices.* A well-developed measurement capability has not been the hallmark of current training devices. Training systems on-line today are characterized by instructor monitoring, control and evaluation of training (manual setup of initial conditions and enroute modifications of the training exercise), with minimal assists from computer scoring of performance or from equipments designed primarily for measurement. Stated simply, simulators designed for training are not utilized in any substantial way for scoring individual or team performance. They are not equipped intrinsically with well-conceived scoring subsystems. The measurement weakness results in most cases from a design approach that emphasizes fidelity of simulation with measurement as a by-product, i.e., picking off and outputing what can be obtained, once the synthetic environment has been created. At most, simple time to perform and system error scores are available, together with communications (audio) records. In some instances, a visual mission-situation display (panorama) is provided for use in reconstructing the exercise after its completion; hard copy records (computer printout of time and event happenings during the exercise) may be provided. In vehicle simulators, provision is often made for recording hardware, the outputs of which are employed as adjuncts to assessment, for example, those which depict a time history of an event or a course of action (flight path recorders to show a plot of ground track, approach recorders to show the path to a radio station, etc.).

In large part, the measurement capability in simulators, particularly those representing surface and subsurface vehicles, has achieved fruition during the development of utilization procedures, once the device is constructed and on-line. Only limited provisions have been made during device design for objective scoring and recording of performance. Also, measurement has served most prominently in providing feedback to the trainee about his performance. The verbal post-mission critique based on instructor judgments about performance usually supported by a situational display of the reconstructed mission, has been a prevailing performance assessment mode.

Several examples of such after-the-fact developments of objective scoring and recording capabilities are summarized next to indicate the basic subjectivity and lack of precision in performance assessment. (Attempts at automatic scoring modes are discussed separately in paragraph 3.5.3.)

A recent example is Device 14A2, ASROC/ASW Early Attack Weapon System Trainer. This ASW tactical team training device employs a system involving three types of performance observation which essentially organize instructor judgments about performance (Dunlap and Associates, 1969).[1] No overall scores or grades are developed for the team. Observations are made solely to determine if the training objectives are met for each training exercise. The three types of performance observation are as follows:

- Checklists are employed for recording the occurrence/non-occurrence of critical events that must be accomplished during each exercise in a graduated training sequence.

- Quantitative scores are obtained on time and accuracy in the team development of fire control solutions and ASROC weapon firings.

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[1] The measurement capability was developed with the current device configuration as a given. Thus, performance observation was the method used for team evaluation in Device 14A2.

- Instructor judgments are assembled primarily on evidence of team coordination (threat assessment, employment of the platform, sensors and weapons) and on the quality of communications (intra- and inter-ship) focusing on content, on anticipation of the information needs of other members and on lateness in conveying information.

Thus, only relatively simple time and accuracy readouts are provided in the device. No hard copy records of performance are available for developing normative data and for school record-keeping.

The performance standards employed center on correctness of team procedural sequences and weapon aim point errors based on error curves. The curves present normative data obtained via computer simulation of sonar operator tracking and target motion analysis at the Attack Director console (UB/plot). The data used in establishing the standards are derived from skilled operator performance under a variety of task and mission conditions.

An example of a submarine team trainer is Device 21A39. This is a simulated FBM submarine attack center team trainer comprising a Mk 113 Fire Control System and associated sonar plotting gear. The purpose of training is to exercise the team in fire control solutions and attack procedures. Since periscope simulation is not provided, techniques of bearing-only solution are used. No attempt is made to train in tactics relating to the positioning of own-ship, choice of weapons or choice of targets in multi-target environments. The index of team performance is fire control solution accuracy. Performance is self-diagnosed; the team determines how well it performed and decides on what the next exercise will be. There is no formal briefing or critique of performance. A large screen display and a hard copy computer printout are used for problem reconstruction. The hard copy printout provides a minute-by-minute account of the following sixteen parameters.

Time (in minutes)
Bearing rate
True bearing
Generated bearing
Actual range
PK range
Actual course
PK course
Actual speed
PK speed
Angle-on-the-bow
Own course
Own speed
Own depth
WG run
Weapon steers

This record provides a fairly precise statement of the relative geometry between own sub and the target. It also provides a basis for determining errors between actual and team-generated values for all relevant parameters. In addition to computer printouts, the device has available an audio tape recorder which can provide real-time recordings of communications over the voice circuits.

The measurement capability is concerned with gross team evaluation (Jeantheau, 1970). The contributions of individuals to the team performance are not isolated; the data base records only the outcomes of team activity. Tactical considerations are not accounted for; the measures are used only to evaluate the team's ability to solve the fire control problem. The measures obtained are the following:

- Range maintenance (cumulative percent of time within range error brackets). Percent range error is plotted against percent of problem time that error is within the range bracket. Thus, performance can be evaluated against any selected error in terms of the amount of time the team maintained range within that error tolerance.

- Range error at time of firing (computed at the minute prior to weapon release).

- Bearing rate maintenance (computed difference between actual bearing rate and PK bearing rate). Bearing rate error is plotted in terms of absolute error.

- Bearing rate error at time of firing (computed at the minute prior to weapon release).

Another example of a device not having an inherent measurement capability at the time of field installation is Device 1BZ2, maneuvering tactics trainer. This is a team trainer which provides instruction in surface ship tactics and, to a limited extent, submarine and aircraft operations as these affect surface ship tactics. Training is provided in the exercise of tactical command, communications, relative motion, close formation tactical maneuvers and the use of tactical publications. Visual presentation is achieved through a projection system controlled from 16 independent control stations (mockup ships' bridges representative of a 2,200-ton destroyer). Each mockup contains a helm unit, a PPI scope, a status board and a two-channel communications system. Each "bridge" is linked to a projector through a computer-driven mechanism which projects an outline of a ship (identified by a letter) on a 16-foot x 16-foot vertical screen. Two instructor stations are provided. Each station has a console which controls and monitors eight ships. Control is limited to voice communication and the ability to take ranges and bearings from any ship in the eight-ship division. One of the consoles is capable of repositioning ships while the other contains the switchboard for the sound-powered telephone system. A measurement system was developed for the purpose of evaluating the effectiveness of the device as a training tool (Jeantheau and Andersen, 1966). Checklists were developed for the four trainee positions to enable instructor judgments about team performance. The following measures were obtained via instructor judgments.

OOD

- Supervisory and leadership capability
- Action taken for maneuvers executed
- Use of proper orders and terminology
- Interpretation of tactical signal
- Maintaining station in formation

JOOD

- Maintaining timely and accurate formation plot
- Maneuvering board solution

RT Talker/Radar Operator

- Use of correct terminology
- PPI scope operation
- RT voice procedure and terminology
- PPI scope operation
- Circuit discipline
- Voice circuit log

Helmsman

- Voice procedure and terminology
- Operation of wheel and engine order telegraph

Team Performance

- Ability to work together
- Adherence to protocols
- General success of team goals

Note that in Devices 1BZ-2 and 14A2, no measures of relative geometry of the vehicles in an engagement, and no hard copy printouts of performance were available. Thus, reliance was placed on instructor observations about performance. In Device 21A39, a hard copy record of relative geometry was available (via design), thus, derived measures of performance were obtainable.

3.5.2 Research Developing a Measurement Capability for Training. As a prelude to the subsequent discussion it is worthy to note that measurement technology has not yet developed to enable the unambiguous assessment of complex human performance in operational systems. Assuming that unlimited types and amounts of information could be acquired, the basic questions that resist systematic solution continue to be: what information is necessary or required? how is the information to be assembled and organized? what kinds of analyses and how often is the performance to be examined? A basic difficulty has been the absence of adequate operational criteria. Due to the absence of effective measurement guidelines and operational criteria, the opinion of experts has been a primary factor in the selection and organization of performance measures. (In our opinion, it is this fundamental lack in measurement technique that has thwarted the design emphasis on automated scoring in training simulators.)

A number of studies have attempted to structure a measurement capability for use in various operational systems contexts. These efforts, most of which have been concerned with flying training, have attempted to improve, in objective, standard ways, the ability to assess the progress and the outcomes of a course of instruction. The results of these studies are of presumable interest to training device design and utilization in terms of the insights provided by the various approaches for defining measures and for implementing scoring procedures.

A variety of studies over the last two decades have reported the development of objective flight checks. In essence, these flight checks (checklist format) comprise both subjective and objective measures of elements of the pilot's job, with subjective judgments made on small, well-defined aspects of performance (e.g., application of power during a maneuver). The first program to obtain detailed and objective inflight proficiency measures (begun in 1939) resulted in the Ohio State Flight Inventory (Ericksen, 1952). Other inflight measurement of performance attempts included the Army Air Force World War II grading system (Miller, 1947), the Air Force Human Resources Research Center program on assessing student pilots (Smith, Flexman and Houston, 1952); the CAA Airline Pilot flight checks (CAA, 1950); the FAA flight checks for airline transport rating (FAA Form 342A) and the airman proficiency/qualification check (FAA Form 3111); the Army Aviation Pilot performance description record (Greer, Smith and Hatfield, 1962) and the Air Force standardization/evaluation checks (for example, SACM 51-4, 1966). As a group, the inflight performance checks have proved lacking for a number of reasons. Less than complete information is provided by the measures and methods. The prevailing approach is that decisions on what aspects of behavior to sample, and when and under what conditions observations are made, are left to intuitive judgment. Measures obtained are often indeterminently associated with overall proficiency. In many instances, measurement is sufficiently difficult that the practice is to obtain what is measureable rather than what is desired. There is also the frequent inability to detect and assess differences in performance when they, in fact, exist. The difficulty continues to be the inability to structure the inflight environment so that accuracy, reliability and validity of measurement are within tolerances.

A program currently under development by the Training Research Division, Air Force Human Resources Laboratory[1] is attempting to build an inflight data recording system and a ground-based automated performance evaluation capability for use in undergraduate pilot training. A T-37 aircraft has been instrumented to record 23 flight parameters from which an additional 8 variables are computed. Figure 41 describes the performance variables selected. The barrel roll and the lazy-8 are the maneuvers which will be initially analyzed.

An experimental program has installed audio/video recording equipment in a training aircraft as a means for assessing pilot performance. This program (Neese, 1968; Purifoy, 1968) developed methods for integrating an airborne audio/video recording system and ground playback equipment into portions of Air Force undergraduate pilot training. The playback equipment included a stock video recorder and an 18-inch screen black and white TV monitor; stock audio/video equipment was mounted in T-37 and T-38 aircraft. This method of recording selected pilot performances served as an adjunct to current training and assessment practices (i.e., no alteration of each instructor pilot's instructional approach) and the measures of performance selected were common with the standard training program to permit comparisons. The twenty-two minutes of tape available during each mission, sampled the maneuvers performed (per mission number) in the ATC flight syllabus for the aircraft. Attempts are being made to correlate these records with instructor judgment ratings.

3.5.2.1 Studies Concerned with Developing an Objective Measurement Capability in Training Devices. Few studies are reported in the literature which bear directly on implementing an objective measurement capability in simulators for assessing training performance. During the 1950s, attempts at objective scoring focused on means for recording portions of tasks in specific skill areas of the pilot's job with the recorded data analyzed at a later time. Determining the feasibility of mechanical scoring methods for simulators was then the vogue (see Smode, Hall and Meyer, 1966, for a summary of these efforts).

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[1] Air Force Human Resources Laboratory, Training Research Division, Wright-Patterson AFB, Ohio.

	PARAMETER	SYSTEM	SENSOR	RANGE	RESOLUTION
1.	Heading	J-4 Compass	Synchro-follower	090-360°	1°
2.	Altitude	Pitot-static	Transducer	0-30,000 ft	
3.	Airspeed	Pitot-static	Transducer	0-350 kts	1 kt
4.	Pitch Angle	MD-1 Gyro	Synchro-follower	0-82°	2°
5.	Roll Angle	MD-1 Gyro	Synchro-follower	0-360°	1°
6.	G Loading		Accelerometer	-1 to +5	.3G
7.	Longitudinal Stick Position	Elevator Cable	Potentiometer	-16° to +24	
8.	Lateral Stick Position	Left Aileron Cable	Potentiometer	±15°	
9.	Rudder Position	Rudder Cable	Potentiometer	±24°	
10.	Pitch Rate		Rate Gyro	90° 1 sec	
11.	Roll Rate		Rate Gyro	180° 1 sec	
12.	Yaw Rate		Rate Gyro	70° 1 sec	
13.	Left RPM	Tach Generator	Frequency converter	0-100%	2%
14.	Right RPM	Tach Generator	Frequency converter	0-100%	2%
15.	Left Throttle Position	Throttle	Potentiometer	0-60°	
16.	Right Throttle Position	Throttle	Potentiometer	0-60°	
17.	Flaps		Potentiometer	0-100%	1%
18.	Landing Gear		Switch	Up or Down	
19.	Speed Brakes		Switch	In or Out	
20.	Thrust Attenuator		Potentiometer	In or Out	
21.	Elevator Tab Up	Trim Tab Switch	Potentiometer	On or Off	
22.	Elevator Tab Down	Trim Tab Down	Potentiometer	On or Off	
23.	Time		Clock	0 - 24 hrs	1 sec
24.	Vertical Velocity		Computed		
25.	Turn Rate		Computed		3 deg
26.	Longitudinal Stick Rate		Computed		
27.	Lateral Stick Rate		Computed		
28.	Rudder Rate		Computed		
29.	Pitch Rate		Computed		
30.	Roll Rate		Computed		
31.	Yaw Rate		Computed		

Figure 41. Recorded and Computed Performance Variables for Inflight Recording System. (USAF Human Resources Laboratory)

To be sure, various proposals have been made for developing complete measurement-assessment packages integral to the synthetic ground environment. These proposals emphasize logical and systematic development, beginning with the precise determination of measurement objectives and culminating in an integrated behavior/measures/scoring hardware array for evaluating trainee performance (see Smode, Gruber and Ely, 1962; Buckhout and Cotterman, 1963; SAE, 1968). However, implementation of such and similar schemes has not been systematically pursued.

Attempts have been made to instrument flight simulators for specific measurement purposes, but utilizing existing on-line trainers. The study by Bowen, et al (1966), cited in paragraph 3.5.3 is an example.

A number of studies have been concerned with analyzing the guidance and control performance in flight simulations employing a variety of measurement approaches. These studies, however, were not structured for training purposes; the simulation served as a test method for deriving performance information. The information objectives included system feasibility demonstrations; comparisons of specific components of the vehicle, development of quantitative models of man-machine performance; vehicle handling qualities investigations; and total system performance evaluation. Representative studies within each of these test methods have been analyzed by Obermayer and Muckler (1964), and they describe the measurement requirements and problems and the differing approaches to appropriate measurement for each of these objectives. In essence, the measurement selection involves three basic categories:

Vehicle stability measures	Response characteristics of the vehicle system
Preference measures	Subjective measures obtained via questionnaire, paired comparisons, psychophysical judgment, or semantic differential (semantic profile)
Response measures	Time history measures and amplitude distribution measures (time on target, RMS, average error, average absolute error, standard deviation)

Obermayer and Muckler (1964) caution, however, that despite the varieties of measures obtainable for the above purposes, none are subject to unequivocal interpretation. So far as the purposes of the present report are concerned, little commonality exists between measurement for training and measurement for system test and development. The approaches described above, however, provide the reader useful information to aid in selecting from among available design alternatives.

3.5.3 Automatic Monitoring, Evaluation and Scoring. The engineering feasibility of automated scoring has been heightened with advances in the design of digital computers employed in simulators, and the current trend in design is towards the development of the automated monitoring, evaluation and scoring capability for training devices. A number of studies have been published concerned with demonstrating the feasibility of automatic scoring and with developing pertinent design requirements. Some are plainly speculative, emphasizing only requirements; others have duplicated certain aspects of instructional requirements in simulators (primarily in the flight context) in order to demonstrate feasibility for design.

However, this automatic measurement capability (computer programing and display and recording of performance information) has not been effectively implemented for purposes of training. None of the published research has been concerned with actual operational trainer implementation. Studies which illustrate the emphasis on design feasibility and on requirements are described below.

Curtiss-Wright Corporation (Benenati, Hull, Korobow, and Nienaltowski, 1962) developed a design for an automatic monitoring system for the flight simulator utilizing available engineering means for recording pertinent mission parameters. Trainee performance was scored on the basis of comparing the parameters monitored withthe programed performance standards, e.g., errors in performance were printed out for use by an instructor. The report was limited to a specification of principles involved in monitoring and scoring selected parameters and did not deal with the design of a proficiency measurement system.

One of the first attempts to monitor pilot performance in the simulator was the UDOFT program (Sylvania, 1963). Using a general-purpose digital computer, this program demonstrated the feasibility of automatic performance monitoring. Several jet qualified pilots flew the simulator in the F-100A configuration from takeoff to altitude and maintained a holding pattern. Pilots were scored on the ability to abort on takeoff and on airstarts following simulated flameouts.

An automatic task sequencing technique was developed in an Air Force study (Kurtzberg, 1963) which presaged a type of automatic programing for task scheduling in simulators. The purpose of the study was to investigate the feasibility of automating the instructor function of sequencing of tasks for presentation to trainees in flight simulators. Algorithms for task sequencing in real time were formulated for two classes of application: training of students for flight vehicle operation (operation teaching mode), and training for development of tactics skills (tactics teaching mode).

Fourteen inflight emergencies were flow-diagramed together with measures of performance and ranking of alternative responses available to the trainee. In the training sequence, tasks were automatically selected and presented, performance compared with established criteria and results recorded, and new task selection made on the basis of the trainee's previous performance. The logic of the technique suggested the possibility of automatic redirection of the training sequence as a function of the trainee's performance threshold of the moment (i.e., adaptive sequencing). The fourteen in-flight emergency tasks and the number of variations of operations for which scores are given are shown below.

Task	No. of Variations
Engine Inlet Icing	5
Instrument Failure Due to Pitot Icing	6
Surface Icing	3
Smoke from Air Conditioner	8
Smoke from Communications Panel	6
Smoke and Fumes Elimination	6
Fuselage Fire	11
Engine Fire While Cruising	10
Fuel Dumping	7
Emergency Descent	9
Bailout	4
Engine Relight	5
Engine Air Start	13
Runaway Stabilizer Trim	18
Total Variations	111

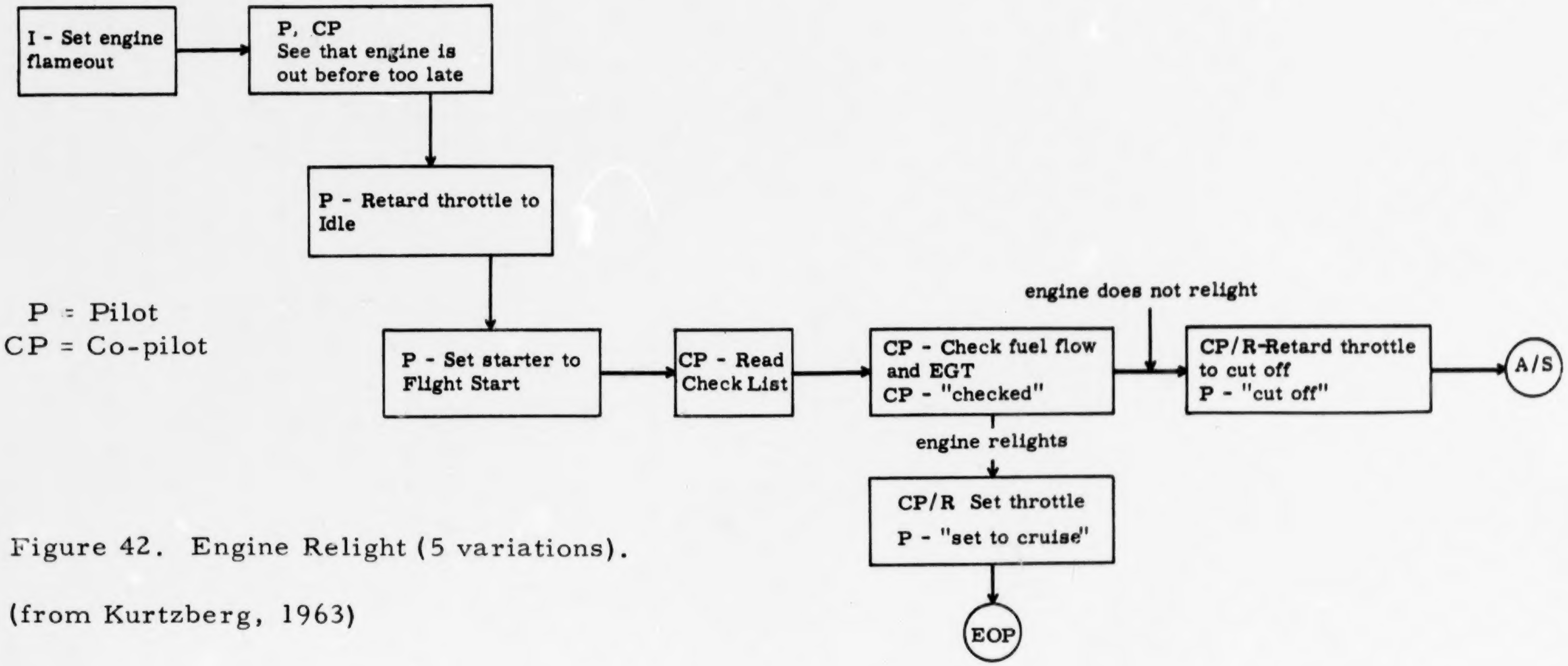
An example of the scoring chart for the task of Engine Relight is shown in Figure 42.

Another example of this trend toward automatic monitoring of pilot performance in simulator training, is the program under development at the Human Resources Laboratory, Wright-Patterson Air Force Base. The research effort is centered on developing a digital computer program for automatically monitoring human performance in the training simulator (Knoop, 1966). The first study in this research-oriented automatic monitoring program (called RAMP) provided an experimental tool for investigating the criterion problem as well as serving as an automatic performance monitoring system. In developing the automatic monitoring program, it is assumed that no quantitative criteria exist. The problem is approached as a programing task, i.e., not accumulating data and

Instructor's Action	Student's Score	Student's Response					
Flameout EGT and fuel	%	See Engine Out	Retard Throttle	Set Starter	Use Check List	Check Fuel and EGT	Throttle to Cruise or C/O
	100	1	2	3	4	5	6
	90	1	2	3	-	4	5
	90	1	3	2	4	5	6
	80	1	3	2	-	4	5
	0	1	2	-	-	3	4
Importance of Steps		1	3	2	6	4	5

Notes:
1. The pilot must spot the flameout before significant RPM is lost.
2. If the starter is never set to Flight Start the engine will not relight.

FLOW DIAGRAM:


I - Set engine flameout
P, CP See that engine is out before too late
P - Retard throttle to Idle
P - Set starter to Flight Start
CP - Read Check List
CP - Check fuel flow and EGT CP - "checked"
engine does not relight
CP/R-Retard throttle to cut off P - "cut off"
A/S
engine relights
CP/R Set throttle P - "set to cruise"
EOP

P = Pilot
CP = Co-pilot

Figure 42. Engine Relight (5 variations).

(from Kurtzberg, 1963)

processing it in a predetermined manner but rather establishing decision-making techniques to accommodate highly variable information on human performance. The computer program is designed to assist in the analysis and determination of performance measures and performance criteria, and using these criteria, automatically monitors human performance. Part of the utility of the automatic monitoring program will be in the evaluation of criteria for flight tasks. These criteria need not be exact and may be easily altered. Of RAMP, Knoop says, initially its effectiveness will depend on the accuracy and detail of the inputs provided by the user.

In essence, the automatic monitoring program is designed to receive inputs regarding criteria, establish requisite matrices for consolidating these inputs, and then monitor the trainee's performance in order to test the criteria. The features of the monitor (implemented by dynamic programing) include: criteria analysis; task sequencing (automatic redirection of the training sequence to provide individualized instruction); and automatic scoring. The intent of automatic scoring is to "free-up" the instructor so that he may perform observations of activities difficult to automate. The technique assumes the existence of a communication channel from RAMP to the trainee.

A second study in this program (Knoop, 1968) was concerned with designing, implementing and evaluating a prototype automatic monitoring program based on the programing capabilities derived in the previous study. This involves the development of a computer program for automatic performance monitoring which enables the implementation of the performance criteria and the performance evaluation techniques that are currently known. A feature of this is the ability to estimate and change, as required, those criteria that are unknown, and allow the instructor to select the types of performance information most useful to him in the instructional role. This is an important design characteristic since no well-grounded body of data exists on relevant and exact performance measures nor are there accepted standards or baselines for assessing performance (i.e., the criterion problem). Thus, the prototype software package for automatic performance monitoring emphasizes easily changed performance criteria and the addition of subroutines for experimentation in criteria evaluation. The program was applied to 5 types of automatic monitoring, using an orbital reentry vehicle model. Knoop defines each of these applications as relevant to flight simulator training. The automatic monitoring program was found to be applicable also to hardware diagnostics and troubleshooting in a simulator training facility. Based on this work, Knoop (1968) feels that, "we are now in a position to recommend, with reasonable reliability, experience, and foresight, the type of program, monitoring capabilities, and the computer memory requirements best suited for an automatic monitoring system for use with flight simulator trainers. The state-of-the-art does not now and perhaps never will permit us to specify, unequivocably, optimal performance criteria, performance measurement techniques, and instructor or trainee feedback for flight missions in general. It is therefore important that automatic monitoring and scoring programs be designed so that advantage may be taken, on a continual basis, of knowledge gained through operational experience with the monitoring system." (p.97). Future research will involve implementing this prototype monitoring system in a flight simulator for field evaluation. Research will also be conducted using the prototype system, augmented by appropriate subroutines to develop methods for evaluating and altering user-defined performance measures, tolerances and criteria automatically as performance data are accumulated.

A study by Bowen, Bishop, Promisel, and Robins (1966) attempted to automate the scoring of portions of the pilot's tasks in Navy training. The research investigated the effects of two training treatments on pilot performance in a Navy Operational Flight Trainer (OFT) simulating the A-4 aircraft. As part of the study objective, scoring devices and procedures were devised (utilizing the on-line OFT) which would provide a reliable basis for assessing pilot proficiency. Two groups of ten pilots each, transitioning to the A-4 aircraft, were given three simulator training sessions spread over a period of 20 weeks. The control group of pilots flew conventional flights; for the same flights, the experimental group received several levels of augmented feedback based on the scoring procedures developed. Knowledge of performance information was given bit by bit (error was identified when made), by numerical grade for each emergency procedure (series of tasks), and by an overall summary score at mission completion. The results indicated that objective scoring information given immediately to the pilot in a useful form, heightened performance. The study, however, was conducted in the operational environment on a "non-interference" basis; hence, problems in strict experimental control were experienced. Matching of subjects in the two groups was not possible. Also, the three OFT sessions were spread over a period of 20 weeks, and the authors contend that so much else was going on in the training course that the OFT experience tended to be "minimized." An enhancement effect for the experimental group cannot be discounted either, since these pilots may have been "urged" to know the emergency procedures well. The scoring instrumentation which was designed and added to the OFT was as follows: (1) A panel of lights which displayed the sequence of events performed during emergency procedures. A buzzer sounded when a sequence was in error. The displayed sequence of events was manually recorded on a scoring sheet. (2) Electric stopclocks were programed to give response times and total time in completing a procedure. (3) A Brush eight-channel pen recorder scored and documented discrete, continuous, and mixed events. Comments made by the trainee or the instructor were also recorded.

Three sets of independent scores of pilot skill in the simulator were developed.

Emergency Procedures Scores:	
S (sequence score)	Number of steps accomplished in a procedural task, weighted for number and difficulty of steps completed and not completed.
P (proportion score)	Proportion of steps correctly accomplished to the total number of steps required (simplified version of the S score).
B (binary score)	Proportion of the number of total procedures correctly accomplished.
Time Scores:	
RT (response time)	Time to complete correctly the first step in a procedure.
TT (total time)	Time to complete an entire procedure.
Aircraft Handling Scores:	
C (control score)	Rating from polygraph records of control effectiveness over aircraft and engine parameters.
Instructor Ratings	Proportion of satisfactory procedures.
Self (pilot) Ratings	Five-point scale for rating emergency procedures, precision flight, and general pilot ability.

The authors suggest that valid simulator measures require that the trainee be exposed to a multiplicity of tasks and events similar to real flight conditions and that the difficulty level be equivalent to the more difficult aspects of real flight. In this way, the pilot will perform in a pattern of priority as in actual flight (e.g., timesharing, attention shifts, anticipation of events, etc.). The pilot would be practicing in a realistic way the actual skill requirements of flight. Means were recommended for objectively recording the following data:

- Procedural sequences and computation of a score which accounts for the relative difficulty of sequential steps.

- Deviations from required flight and engine parameters. Such data may be inspected for radical deviations or used in a computational program as part of a score for manual control.

- Response time to unexpected situations.

- Accuracy of precision flight, including a composite score.

- Accuracy of navigation.

Finally, the scoring devices should possess a high-speed capability with hard-copy printout in near-real time. A computer-based system is preferred because of the need for updating and improving the various scoring and recording programs.

3.5.3.1 The New Breed. The planning for new synthetic training systems makes provision for the automatic monitoring, evaluation and scoring capability when relevant to the purpose of the training. Two examples are provided to indicate the innovative design features and elements of the measurement system.

3.5.3.1.1 Synthetic Flight Training System, Device 2B24. The design of this helicopter instrument flight trainer is based on automated training concepts. These are applied to decrease the number of instructors needed, to provide individualized instruction in a multi-station trainer, to produce a standardized product, to allow proficiency advancement in part, through adaptive sequencing and to provide objective and comprehensive performance evaluation (Hundt, 1969). The core of the system is the computer programing which drives the simulator to provide preprogramed scenarios and which provides for automatic monitoring, evaluation and scoring of performance, displayed via computer-generated CRTs with hard-copy records of performance. A summary of the system elements and a resume of the innovative design features for training are presented below.

The simulator operates in three modes:

- Automatic mode--This is the primary mode and includes adaptive sequencing.

- Semi-automatic mode--The instructional burden is greatest in this mode, since training strategies are under instructor control based on assists from the automatic monitoring, evaluation and scoring subsystem.

- Checkride mode--This is the standard evaluation mission(s) and instructor involvement is minimal.

The instructional functions include the following:

a. Briefing and demonstration--This requires the selection of briefings and demonstration of flight maneuvers from a tape library.

b. Student practice monitoring and support--The selection of practice material for imparting procedures, knowledges and skills to trainees and the gathering of data necessary for assessment is involved here; a training strategy is developed for each student to achieve a reasonable learning rate.

c. Assessment--Computer programs provide assistance by displaying out-of-tolerance conditions, and initiating problem freezes when conditions warrant; the instructor also has records of ground track, altitude, airspeed, excesses in safe operating limits, communications, and a display of the last five minutes of performance; the instructor monitors the problem displays, monitors the error information displays and communicates with students.

d. Guidance--Based on the problem situational display and performance error display, the instructor options include: verbal guidance, problem freeze with guidance/demonstration based on the diagnosis of error.

e. Debriefing--This includes debriefing of a flight segment (involving such assists as tape records of voice procedures, record of ground track, error excesses, and other indicants); and total evaluation at exercise completion (involving performance as a whole, error measurements, and scores identified via hard-copy printouts and plots).

A number of instructional assists are provided to unburden the instructor in operating the simulator and to better enable him to select options conducive to effective instruction. Only those assists which represent innovations for training are described next; their availability, of course, varies as a function of the training mode being employed.

a. Auxiliary information display--This CRT presents alphanumeric information (in page formats) describing training in progress, the status of individual trainee stations or prevailing environmental conditions. A keyboard and light pen enable the instructor to access the computer in order to modify training or simulation conditions (e.g., malfunction insertion/removal, modify environmental conditions, select and reinstate initial condition parameters, freeze parameters of flight individually, etc.). The functions performed with this computer-generated display include the following:

- Initialize the trainers
    - select/modify initial conditions
    - select malfunctions
    - modify performance alerts
- Monitor and control flight parameters
    - monitor flight parameter status
    - change/freeze/restore a flight parameter
- Monitor and display radio navigation station
- Recall of stored plot for coaching/debriefing

b. Graphic Plotter Display--This is a graphic CRT display (one for each trainee cockpit), which presents a plot of ground track, time-based plots of altitude and airspeed, and selected status information.

c. Closed Circuit Television system (CCTV)--The components of this cockpit monitoring system are:

- TV camera (one in each cockpit)
- Video tape recorder
- CCTV monitor (one in each cockpit and two at the instructor console)

d. Record/Playback system--This equipment records student performance for the purpose of playing back a copy of just completed performance (i.e., self-confrontation technique).

e. Hard-copy printout system--This information is used for performance assessment in the critique. A sample information content includes the following:

- Time of event occurrence
- Exercise segment in which the condition occurred
- Difficulty level (adaptive) of exercise
- Parameter which went out-of-tolerance
- Maximum parameter deviation during out-of-tolerance

- Time (seconds) difference between initial and maximum deviation during out-of-tolerance
- Number of seconds maximum deviation held
- Number of seconds required for aircraft to return to in-tolerance from maximum deviation

f. X-Y plotter--This is used in making permanent records for the quality control of performance errors for each training session. Performance error parameter totals and cumulative times will be recorded for:

- Individual error parameters regardless of maneuver
- Error parameters per type of maneuver
- Groups of trainees

The system highlight is the computer programing with computer generated CRT displays and appropriate controls. Classes of performance status and errors are continuously available. Trainee performance on parameters/maneuvers is compared against the preprogramed ideal performance (for given parameters, etc.), plus or minus the tolerances designated, and trainee error data are automatically recorded and available for display either as accrued or on demand. Through automated equipment assists, the instructor is provided opportunities for instructional control and for developing optimum training strategies for each independent student in a multi-student environment.

3.5.3.1.2 Simulator for Electronic Warfare Training (SEWT). A recent requirement for a Simulator for Electronic Warfare Training (SEWT)[1] specifies an automated monitoring, evaluation and scoring capability. The highlights of this capability are summarized below in terms of a design philosophy on which the system is predicated.

- Computer programing which drives the simulator to provide a preprogramed mission scenario, the monitoring of all aspects of performance and relay of selected knowledge of performance information to students, and hard-copy records of performance both for in-mission and post-mission critique and for school records.

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[1] RFP number F33657-69-R-0994, Simulator for Electronic Warfare, U.S. Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, 25 August 1969.

- An instructor capability to monitor and evaluate performance, and provide enroute mission instruction and post-mission critique to four students who are performing independently. Computer-generated CRT displays provide student performance information.
- An ability to present preprogramed standardized mission scenarios that are graded in difficulty over the course of instruction and which can be modified during each training session.
- Automatic evaluation and scoring of student performance which enables the instructor to develop training strategies that are optimum for each student. This capability permits each student to progress at his own pace in achieving the training objectives per mission.
- Flexibility in employing the simulator for training and evaluation purposes.

Automated evaluation and scoring with scoring criteria adjusted to the stage of training of each student provides information for monitoring and error indications which are displayed to the instructor. He uses these directly in evaluating and controlling each student's progress. The instructor options in developing the training strategies are listed below. These are the changes that can be made to the preprogramed mission either by event or time access via displays and controls on the instructor console. Instantaneous and past-history information on any student's performance can be called up from storage.

- Continue preprogramed mission, no action required.
- Provide verbal feedback of performance information to selected student based on monitoring information obtained from CRT displays. This may be in the form of knowledge of results of performance or cues to the student for enhancing performance.

- Freeze the problem for any or all students and provide verbal guidance, or freeze the problem until all students have completed certain requirements; resume mission.

- Demonstration mode--Freeze the mission either to demonstrate preprogramed emitter signatures to all students or to demonstrate specific characteristics of the preprogramed emitters for any or all students when performance is below expectations for the specific mission number; resume mission.

- Reinstruction mode--Freeze the mission for any or all students when performance is below expectation for the specific mission number. The reinstruction requires that the student refly a leg or phase of the mission. The mission is restarted at the point of the refly position. This mode can be played in slow time (1/4x, 1/2x) and in real time.

- Error alert mode--When a student exceeds the error envelope in the mission for a class of error, an automatic problem freeze occurs at the time the next error of the same class is made by the student. The instructor has the choice of manually overriding the computer freeze or accepting the freeze. His instructional options are those indicated above, vis-a-vis the training strategy he is developing for the student in question.

- Insert new emitter parameters--when a student's performance exceeds the mission scenario requirements, the instructor has the option of inserting new emitter characteristics in addition to those in the preprogramed scenario. This is an adaptive capability by which problem difficulty can be increased to keep any student at the threshold of his ability at any given time.

- Insert airborne intercepts (A/I's)--two classes of preprogramed A/I's are available. One class will be displayed to each student and come on automatically unless the instructor elects to override this event, causing it not to emerge. The other class, although programed, will not come on unless commanded by the instructor when the acceptable position for initiation on the flight track occurs. The A/I insertion can be controlled to achieve the standard scenario and also can be adaptively controlled to account for individual differences in skill among students.

- Insert in-flight malfunctions--The rationale here is the same as for the airborne intercept insertion.

The heart of these operations is centered on computer programing with computer-generated CRT displays and appropriate controls. An alpha-numeric CRT presents classes of student errors, as accrued, continuously throughout the mission. A GRID CRT (i.e., CRT with light pen control) allows a diversity of performance information to be displayed (both alpha-numerically and pictorially) via standardized CRT page formats. Six basic display and control modes are available.

- Monitoring and error evaluation mode
- Error alert mode
- Basic monitoring mode
- Demonstration mode
- Airborne intercept control mode
- Malfunction insertion mode

In essence, the instructor is provided the capability for evaluating performance throughout the mission to obtain information on which to base decisions either to proceed as preprogramed or to modify the scenario (in the events presented for training) or to modify the mission time (via problem freezes). The structure and control of training is based on determining when any student is out of error tolerance with the performance standards for the mission being flown, both for the mission preflight setup procedures and when operating in the emitter environment. It is also based on determining when any student's performance exceeds the performance standards set for the mission being flown.

3.5.3.2 Design Features for Implementing Automatic Scoring in Training Simulators. This subsection considers what is perhaps the most crucial design concern of the immediate future, that of providing an automated measurement capability in training devices. The development of automatic scoring systems must resolve a number of design problems to achieve successful implementation. Unfortunately, not much useful data pertinent to these issues are available. Guideline data for design specification are: 1) notably absent because the published research has not dealt directly with the use and implementation of automated scoring for purposes of training, or 2) difficult to provide because of a number of system-specific requirements that are pertinent to any given training simulator. In a real sense, these issues generate the need for considerable research to resolve a number of difficult decision points for design.

Thus, our approach is to identify the classes of problems that must be resolved and what actions are required. The design issues which follow are among those of greatest significance to the design of automatic monitoring, evaluation and scoring.

3.5.3.2.1 Data Requirements for Derived Measures. An initial effort is needed to determine the raw data requirements from which derived scores will be obtained. The basic approach is to develop quantitative expressions based on training requirements information. These requirements are system-specific, correlated with the class of training device under consideration and with the training objectives. The parameters to be sampled describe the interrelations among own vehicle, the target and the media. The parameters recorded relate to classes of data specific to types of training devices. For example, vehicle management parameters are of most importance to instrument flight trainers whereas tactical employment and load (e.g., vehicle units in an engagement) parameters are of significance to tactical team training devices. The relevant parameters reside in the following classes of data.

a. Vehicle management--This class of recorded data refers to vehicle positioning and power plant management parameters. For example, for device 2B24 (helicopter instrument flight trainer), the performance parameters to be recorded during automatic mode operation include:

- airspeed
- altitude
- flight path
- rate of climb
- rate of turn
- pitch attitude
- bank attitude
- rotor RPM
- gas produced RPM
- EGT

b. Relative geometry considerations--This class of data is concerned with own-vehicle position and action direction or with an emplaced unit (e.g., carrier aircraft controller) in relation to other units/vehicles in an area of engagement or involvement. For example, in surface or subsurface vehicles the important parameters include the variations in range and bearing data (course, speed, depth maintenance or change), and rate of change of these relationships (closing, opening rates, etc.). For a fixed or emplaced unit (GCA or carrier control of aircraft) the parameters of concern include the specific aircraft in relation to the recovery site and the positions and movements among aircraft in a defined pattern.

c. Tactical employment of vehicle--These data refer to the relevant parameters in the basic detection-to-engagement paradigm, involving own vehicle, friendly unit(s) and target vehicle(s). For example, in surface ship ASW training, the relevant parameters inhere in sonar detection and classification, in attack director operations involved in developing the fire control solution, and in certain Combat Information Center operations (e.g., CIC plots) in support of operating the ship as a fighting unit.

d. Load--These data relate to the amount of "clutter" (i.e., number of things) involved in a training situation, and include, the number of different units in an engagement (support units, friendly units, targets), command relationships (HUK forces, SAUs, etc.), and communications requirements.

e. Weapons employment--These data refer to the parameters recorded on weapon selection and preparation and on relevant weapons actions (e.g., water splash point for surface to subsurface missile, torpedo launch and course; countermeasures).

3.5.3.2.2 Selection of Measures. The measures selected are based on the specification of the knowledge or information wanted about performance. Initially, measurement is concerned with determining that the critical task events have occurred correctly. In inadequate, then diagnostic measures are needed to indicate the nature of faulty performance. Usually, well-stated training requirements suggest quite easily the corresponding measures and specific performance criteria. Measurement must determine if these criteria have been met within the tolerances specified. The parameters selected are scored and compared to some standard to derive the type of measure desired. One of the problems in programing the computational system is determining what aspects of performance are to be included in the measure.

Derived measures are specific to the types of training systems, i.e., those having similar training purposes. Obviously, a variety of measures are available and no useful ways are suggested economically for capturing and organizing the types and arrays of measurement possibilities. Thus, our approach to the discussion of measure selection for machine scoring will center on classes of measures pertinent to types of training devices in the NTDC inventory. In essence, these classes of measures can be organized as follows:

- Manual control of vehicles--Measures of vehicle positioning and tracking, primarily flight vehicles with some concern for surface and undersurface vehicle control (e.g., maneuvering, docking, etc.).

- Procedures following--Measures pertinent to any training device class in terms of time/event sequences (errors of sequence, omission and commission of activities, and inappropriate timing of activities).

- Decision making--Measures pertinent to actions involved in tactical operations (e.g., search and attack options in an ASW course of action), and measures pertinent to individual performance relative to tactical employment of a vehicle.

- Team performance--Measures pertinent to the coordinated performance of groups in defined mission contexts.

a. Manual Control of Vehicles--Several kinds of single axis error amplitude scores are widely employed in describing manual control (tracking) performance. Those used most prominently are proportion of time-on-target, root mean square error (RMS), average error, and average absolute error. Table 27 indicates the principal error amplitude scores and corresponding equations for discrete (non-tracking) measures.

Kelley (1969a), states that assuming a Gaussian distribution, RMS error is the most reliable estimate of dispersion since this score has the least relative sampling error of the measures of dispersion. Average absolute error is also a reliable measure of dispersion. Proportion of time on target scores are less reliable than the former two. Reliability is influenced by the size of P_{tot} (i.e., target zone). Bahrick, Fitts and Briggs (1957) indicate that summed time-on-target yields a measure which varies nonlinearly with the size of the target area (i.e., the shape of the learning curve changes nonlinearly as target size changes). Thus, too low or too high a time-on-target score range in undesirable. They suggest that the optimum target zone includes about 68% of the tracking distribution.

There are various techniques for combining error amplitude scores. The most important of the multi-axis error amplitude scores is shown in Table 28. Kelley (1969a) provides a detailed discussion of the characteristics of these measures and the conditions for their use.

The frequency characteristics of tracking performance may be used to yield information on effort expenditure in performance. Two performances may be the same in terms of some amplitude score yet may be quite different in the amount of effort in achievement. Frequency measures also provide indications of how the trainee is solving the control problem. Simple frequency measurements include zero crossing error, zero crossings of the derivatives of error, and the instances when a defined

TABLE 27. Fundamental Equations for Continuous Tracking Scores, with the Analogous Equations for Discrete Measurements.

Tracking Score	*Discrete Score*
Mean $\overline{E(t)} = \frac{1}{T}\int_0^T (X_d - X)dt$ (usually assumed to be zero in tracking)	*Mean* $\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$
rms Error $E_{rms} = \sqrt{\frac{1}{T}\int_0^T (X_d - X)^2\,dt}$	*Standard Deviation* $\sigma = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(\overline{X} - X_i)^2}$
Average Absolute Error $\overline{\lvert E(t) \rvert} = \frac{1}{T}\int_0^T \lvert X_d - X \rvert dt$	*Average Deviation* $AD = \frac{1}{n}\sum_{i=1}^{n} \lvert \overline{X} - X_i \rvert$
Proportion of Time on Target $P_{tot} = \frac{T_{ot}}{T}$	*Proportion of Scores within Tolerance* $P_{swt} = \frac{n_{wt}}{n}$
Legend	
Continuous $X \equiv X(t) =$ a continuous tracking sample $T =$ length of tracking sample $X_d \equiv X_d(t) =$ desired value of X; when X_d varies with time, $X_d(t)$ is the forcing function that is tracked $E = X_d - X$ $\lvert E \rvert = \lvert X_d - X \rvert =$ absolute error $T_{ot} =$ length of time on target during trial of length T	*Discrete* $X_1, X_2, \ldots, X_n =$ a sample of discrete scores $n =$ number of scores in sample - - - - - - - - - - - - - - - - $\lvert \overline{X} - X_i \rvert =$ deviation (absolute) from the mean $n_{wt} =$ number of scores within tolerance

(from Kelley, 1969a)

TABLE 28. Multi-Axis Error Amplitude Scores

Weighted Time-Averaged Error for n Independent Axes

$$\overline{E}_m = \frac{1}{T}\int_0^T (a_1 s_1 + a_2 s_2 + \ldots + a_n s_n)dt$$

$$= \sum_{i=1}^{n} a_i \overline{s}_i$$

Independent axis errors may be summed and then time-averaged or time-averaged and then summed.

Instantaneous Vector Error in n Axes (Scaled)

$$E_v = \sqrt{a_1^2 E_1^2 + a_2^2 E_2^2 + \ldots + a_n^2 E_n^2}$$

Multi-Axis Time-Averaged Vector Error (Scaled)

$$\overline{E}_v = \frac{1}{T}\int_0^T E_v(t)\, dt$$

$$= \frac{1}{T}\int_T (\sqrt{a_1^2 E_1^2 + a_2^2 E_2^2 + \ldots + a_n^2 E_n^2})dt$$

Multi-Axis rms Vector Error

$$E_{vrms} = \sqrt{\frac{1}{T}\int_0^T (a_1^2 E_1^2 + a_2^2 E_2^2 + \ldots + a_n^2 E_n^2)dt}$$

Multi-Axis Time on Target

$$P_{mtot} = \frac{T_{mot}}{T}$$

Multi-Axis Vector Error Time on Target

Employs equation for single-axis time on target, with the target band defined in terms of E_v, the instantaneous vector error. To avoid the continuous square root operation, the square of the vector error may be employed and compared to the square of the desired target zone.

Time-Averaged "Largest Error" Multi-Axis Score

$$\overline{E}_m = \frac{1}{T}\int_0^T E_m dt$$

Legend

$s_1, s_2, \ldots, s_n$ = instantaneous individual axis errors ($|E|$, or E^2)
$\overline{s}_1, \overline{s}_2, \ldots, \overline{s}_n$ = time-averaged error for each axis,
$a_1, a_2, \ldots, a_n$ = weighting or scaling coefficients for the scores in each axis
T = length of the tracking trial
E_i = instantaneous error in the ith axis
P_{mtot} = proportion of time on target in all axes simultaneously
T_{mot} = length of time when no axis was out of tolerance during trial o length T
E_m = value of the largest absolute instantaneous error of any axis

(from Kelley, 1969a)

criterion of error is exceeded. (See Fitts, Bahrick and Bennett, 1956; Obermayer, Swartz and Muckler, 1962.)

There are also measurement techniques employed by control engineers for measuring tracking performance. These include the measurement of input-output relations (describing functions), crossover models relating frequency and amplitude of response, and parameter adjustment for model matching (match between output of the human and that of the model). Reviews of these techniques and other approaches can be found in Kelley (1969a), and McRuer and Jex (1967).

b. Procedures following--This general class of measurement is pertinent to all types of training devices and basically involves the adequacy of time and event sequences in task or mission performance. The scoring concerns errors in sequencing, omission/commission of activities, and inappropriate timing of activities. The common usage of time and event scoring and recording (e.g., time and event hard-copy printouts) precludes the need for much discussion. One example is provided concerning Electronic Warfare Training in the emitter environment phase of a defensive (airborne) mission. An example of the measures that may be computer scored is shown below.

Switch setup in signal analysis

Switch position in detection (signal to be countered)
Time to detect
Failure to detect
Cue buildup (onset of signal to action)
Switch position in identification (wrong emitter)
Time to identify type of signal
Mode of operation in switch settings

- receiver
- transmitter
- expendables

Malfunction correction sequences
Total number of signals countered

Threat assessment

Switch positions
Time of handling threat

Setup for jamming

Switch positions on jamming systems
Time to set up

Initiation of jamming

Time at which jamming is initiated
Time during which jamming is effective

Use of expendables

Switch positions for selecting expendable dispensing programs
Time to initiate
Time at which expendable program is terminated
Failure to release expendables
Maintenance of minimum stores level

Threat priority

Signals attended to in time
Switch positions
Time of handling new, higher priority threat (cue buildup)

Environment Coverage

Signals or bands covered
Jammer refinement switch settings

  initial
  subsequent

Number of jammers on individual signals or bands

Evasive maneuvers

Maneuver selection
Time of initiation

c. Measures describing tactical decisions--Of concern here, are measures appropriate to the tactical employment of vehicles, particularly as applicable to surface and subsurface tactical team trainers. At present, no provision is made in these training devices for an automatic measurement capability (see paragraph 3.5.1).

Tactical decision-making presents difficult measurement problems, primarily due to the nature of decision-making activity. While the antecedent operations are complex, the overt acts are relatively simple. It is also unlikely that a given tactical decision can be judged right or wrong in the absolute sense (except in the event of obvious errors based on the relative geometry of a situation). Consider, for example, the case of own-ship holding contact on a hostile target where own-ship's weapons have a greater probability of kill as range is closed. Obviously the closer own-ship gets to the target, the more likely is a successful attack, but the more likely is own-ship to be attacked by the target or the more likely is the target to carry out its primary mission. In such a situation there is no obvious single "right time" to attack. (Thus, the outcomes of the decisions must be explored to identify the factors involved in reaching the decision.) Similarly, in search and attack operations, there may be several equally good solutions based on the combinations of search and attack procedures employed. The point to consider, however, is that there are but a limited number of "good" solutions and also obviously incorrect solutions for a given situation.

Several classes of quantitative part-task measures can be employed to achieve indications of the adequacy of tactical operations. To be successful, they must be based on precise mission models of engagements which identify the lawful alternatives for success. These classes of measures which are mission-specific in their detail are as follows:

- Positioning of vehicles--These involve time history plots of relative geometry based on course, speed, depth/altitude changes (e.g., maintenance of positions, closing/opening rates involving bearing and range changes).

- Time and event happenings--These refer to mission events upon which decisions are based, e.g., sonar detections and classifications, radar detections, achievement of fire control solutions, CIC evaluations, etc.

- Selection of weapons or of a course of action--These involve the selection and employment of resources (launch time of specific weapons, release of countermeasures, etc.), or the selection of available (defined) search options (e.g., ASW "Oak Tree" search pattern) and attack options (e.g., "Geo Sector" ASROC launch).

- Coordination with other units--These refer basically to inter-ship communications involving type of and time of messages disseminated.

- Appropriate response sequences--The in-tolerance response sequences must be correlated with the mission model since there may be a finite number of equally good sequences to achieving terminal solutions.

d. Team Performance--The measurement of team performance is a difficult undertaking for a computer scoring system. A basic problem is the manner in which team training is conceptualized. When team interaction is viewed as a sequence of properly planned and executed individual actions, that is, a job position orientation with explicit tasks assigned to each member and with sequences of performance required to carry out defined mission tasks (e.g., two or more man air crews), then measures of system output may be sufficient. When team coordination, however, refers to the extent to which members interactively perform in situations where there are no predetermined standards of performance (i.e., team operations characterized by emergent situations (Boguslaw and Porter, 1963), then procedures tend to be developed by the team rather than imposed on the team. Teams may be equivalent in overall performance yet differ considerably in procedures and in self-organization. Several equally good solutions to problems usually exist and inter-team differences in procedures become evident in coping with the environment. When the development of coordinative skills is stressed based on adequate individual skills in each trainee's position, measurement is difficult and unreliable. A summary of team training assessment attempts can be found in Smode, Hall and Meyer (1966).

One attempt at describing this performance has been through examining team communications (the equipment requirements for this involve only an audio recording and controlled playback capability). A study by Krumm and Farina (1962) developed communication measures as one means of defining crew coordination in the B-52 integrated simulator facility (an MB-41 flight simulator electronically linked to an APQ-T2A Ultrasonic Bomb-Nav trainer with a crew of two pilots and two navigators). Measures were taken of volume (production of message units) and pattern (kinds of message units such as voluntary inputs, acknowledgements, etc.). The communication scores, however, were found not to be unequivocally acceptable as a criterion measure. Siskel, Lane, Powe and Flexman (1965) investigated communication processes in actual B-52 and KC-135 flights. The mission segments chosen for analysis were the takeoff and the bomb run for the B-52, and takeoff and aerial refueling for the KC-135. The hypothesis that more experienced crews would show lower communications rates (transmissions and messages) than less experienced crews was not confirmed.

Studies by Federman and Siegel (1965) and Siegel and Federman (1968) examined the communications of anti-submarine warfare (ASW) helicopter crews (pilot, nav-copilot and sonar operator) while performing tactical flight problems. In the first study, two tactical flight problems were developed for use in device 15R10 (ASW helicopter trainer). Data were collected on twelve helicopter teams (a team consists of two crews).

Fourteen unitary communications predictors of performance proficiency were isolated and found to be directly related to miss distance (i.e., distance of weapon impact point from target). These communications variables, presented as ratios, were:

- Activity messages/N[1]
- Evaluative messages/N
- Confusion risk willingness/Reluctance to confusion risk willingness
- Directing messages/Requests for directions
- Nonrequested messages/N
- Phenomenological messages/N
- Invitational messages/N
- Phenomenological and invitational messages/Objective messages
- Progressive messages/Regressive messages
- Requests for information/N
- Provides information/N
- Requests for opinion/N
- Provides opinion/N
- Voluntary opinion/N

A factor analysis of these 14 unitary communications predictors yielded four factors which were labeled: probabilistic structures; evaluative interchange; hypothesis formulation; and leadership control. The second study replicated the first study but used device 14H4, ASW Helicopter simulator. The findings of the first study were verified and four additional unitary communications predictors were identified. These were:

evaluative/activity
concordant/discordant
corroborated/N
extrapolation/N

Three of the four factors identified in the first study were found to be congruent; the fourth factor, hypotheses formulation, was not confirmed by the second study. Based on this verification of the generality of the factors, a course of training for ASW helicopter pilot in the use of the emergent communications factors was developed, administered and evaluated. The logic underlying the research is that measurable communications entities exist which may be employed in improving ASW proficiency.

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[1] N is equal to the total number of goal-oriented communications.

As a group, the various researches on communications measures as indicants of team performance have not yielded much information for measurement purposes and the value of this approach for automated measurement is unclear. Perhaps the most useful statement to be made is that team coordinative measures of performance, other than measures of system output, do not lend themselves to automatic scoring, and are best accounted for in the post-mission critique session via instructor judgments.

3.5.3.2.3 Data Sampling Rates. An important design consideration is performance sampling rate. The issues concern: how often the measurement data are sampled in the training exercise; the length of time each sample is examined; and the places in the mission scenario wherein the sampling is conducted. These decisions are correlated with computer "space availability" for the purpose of scoring performance. Logically, the sampling time for defined tasks (e.g., a 90° level turn at a rate of 3°/sec) is set to include that complete performance; for more or less continuous controlling (e.g., maintaining altitude or heading in turbulence), the sampling time must be based on other logical considerations, derived usually from experience. For example, the SFTS (device 2B24) is programed to measure performances in ten-second interval samples. The question of the reliability of the sampling intervals must be considered carefully in terms of minimum man-system response times and in terms of specific task characteristics (e.g., aircraft roll oscillations of three seconds per cycle should be sampled for several complete cycles per interval).

3.5.3.2.4 Error Tolerance Criteria. Means are required for inserting error tolerance criteria into the computer (pre-mission) and also to modify error criteria during a mission, as required. For example, with preprogramed scenarios, error tolerance criteria may require modification manually on-line as a function of student performance per stage of training. In the case where a student exceeds the preset error tolerance and a computer freeze occurs (i.e., an error alert mode), the means must be provided via keyboard address to the computer, etc.) to override the previous error criteria and modify (as required) by inserting new tolerances to enable the continuation of the exercise according to the training strategy elected by the instructor.

The question of suitable criteria to use for error determination in the computer is an issue of concern and guidelines for design are indeterminate. Most often, these criteria are based on what subject matter experts consider good performance (i.e., preconceived notions of ideal performance). However, criteria should also be based on what good job incumbents actually do during task operations. Criteria established on this basis requires the collection of normative data from samples of actual job performance. Fortunately, computer programing techniques enable error criteria modification on-line as experience with the training system accumulates. Even if specific values for parameters are unavailable, memory space can be reserved and used as data are collected.

3.5.3.2.5 Organizing the Measurement Data. The computer is utilized for scoring, evaluating and recording performance. Time histories of performance are easily obtained as is information on event or status situations due to their binary nature. Frequency data are likewise easily assembled and manual control scores (e.g., integrated error rates) can be quickly computed. Larger segments of performance and terminal (system) outputs are also achievable directly. The computer is also able to combine, integrate and weight scores and compare the results against defined error tolerance criteria. Computer-generated displays and hard-copy performance output records are available to present feedback of performance information to the trainee and performance and error information for instructor monitoring through output devices. The instructor is also able to perform as a link to the computer for trainee performances not easily processed automatically and he is able to access the computer directly for performance error and status information via input devices (e.g., typewriter, light pen). In essence, automatic, monitoring, evaluation and scoring can be accomplished with facility. Thus, the design decisions to be made concern the following:

- Combining, integrating the performance dimensions/parameters scored.
- Weighting of scores and priority ranking of scored performance for error and situational display at the instructor station.
- Providing feedback of performance information to the trainee (error presented immediately as accrued, on primary or secondary displays in the trainee station).
- Display of performance information (error and situational) via computer-generated CRTs at the instructor station. Care must be exercised in specifying the performance information to be displayed in terms of successive page formatting (alpha-numeric and situational display of error and status) for the various instructional modes (e.g., monitoring and control, evaluation, demonstration, reinstruction).

- Formatting requirements for retrievable (hard-copy) records of all error scoring and the time and event happenings throughout the exercise. The permanent record is of two types: student critique, and school record-keeping. Since the computer is capable of recording all time and event happenings that occur in the mission, all factors that relate to human performance can be provided via hard-copy printout. This printout can be to the level of any switch which is changed by the student in the exact sequence of manipulation or only to the level of significant action events. Any level of call out can be specified.

    - Time and Event Printouts--present the total performance indicants, and are used in school record-keeping functions. An additional use is in evaluation (checkride) missions where detailed indications are desired on the progress and outcome of the mission.

    - Total Error Printouts--these are complete error printouts across mission time and are used for critique of training. Error indications are presented by classes and trends of errors are identified.

    - Summaries of Error Scoring--these are also used for critique purposes, in the instructional sense, since they represent short summaries of errors made per error class, scores achieved per mission segment, total score for the mission, etc. The value of this type of single-page summary per mission is that a file on each student can be kept simply which can be used in diagnosis of performance error as well as for trend depiction.

3.5.3.2.6 Summary. The achievement of automated performance measurement systems in simulators has been hampered by major obstacles. A recurring problem has been criterion determination, that is, the need for quantitative baseline values with which performance data may be compared for purposes of evaluation. Another major problem has been the determination of what measures best describe performance and what variables relate significantly to effective performance. Buckhout and Cotterman (1963) enumerated some key (and still valid) requirements for the development of an automated scoring capability. Beginning with an understanding of the purpose and the use of the scores, defining, and classifying the behaviors to be measured is an initial undertaking. Means for quantifying these behavioral elements must be established. Thus, the job must first be partitioned into manageable units of behavior (tasks, task elements, etc.) which are observable and (in most instances) quantifiable. Criteria or standards of performance must then be developed since quantifying behavior involves examination of mission requirements and selection of those parameters which are useful in evaluation and which can be efficiently obtained. Following this, the scores must be tested to see how well they predict performance, i.e., was the correct selection of scores made? Finally, how well the scores stand up under repeated use must be determined. This systematic development is a big order, since methodologies are lacking to accomplish each of the requirements completely. The problems of automatically scoring the critical, meaningful aspects of complex tasks have not yet been thoroughly analyzed. The research needs include: selecting or developing recording procedures, selecting measures, developing testing programs, determining the applicability of measurement operations to task structure, and predicting mission performance. It is not simply a problem of identifying and using available scoring equipments.

3.5.4 Automation of Instructor Functions. An emerging theme in the design for the management of training in simulators is the automation of instructor functions. This is a design goal that is just beginning to be examined in terms of implementation. It merits a notation here since this concept and approach to training system design is predicated on an automatic monitoring, evaluation and scoring capability. Two research programs, currently underway, both utilizing the flight simulation context are provided here as examples of this innovation of the future.

The feasibility of developing design guides for automating various instructor functions has been reported by Leonard, Doe and Hofer (1969). This study investigated the problems involved in building an automated weapon system trainer with the objective of determining what training functions could be automated within limits set by the state-of-the-art in computer technology and in training theory. The F-4 aircraft characteristics and procedures were utilized as the basis for this study. Five specific flight segments were analyzed in terms of training needs and a training approach was developed for each of these flight segments. The flight segments were: instrument flight maneuvers; ground controlled approach; offset bombing; navigation; and takeoff, climb and emergency procedures. For each of these segments, techniques were described for structuring training sequences, based on a WST program language (WPL). Design guides were developed for automatic: trainee performance monitoring; trainee performance evaluation; task difficulty modification (adaptive); and exercise preparation. In essence, the steps in the development of the program language is shown in Figure 43. The authors believe that, "although nearly every aspect of training can now feasibly be automated, the major job of effectively doing so is very complex, even though straightforward. This complexity, coupled with an unavoidable uncertainty about human behavior, implies that training program construction will not

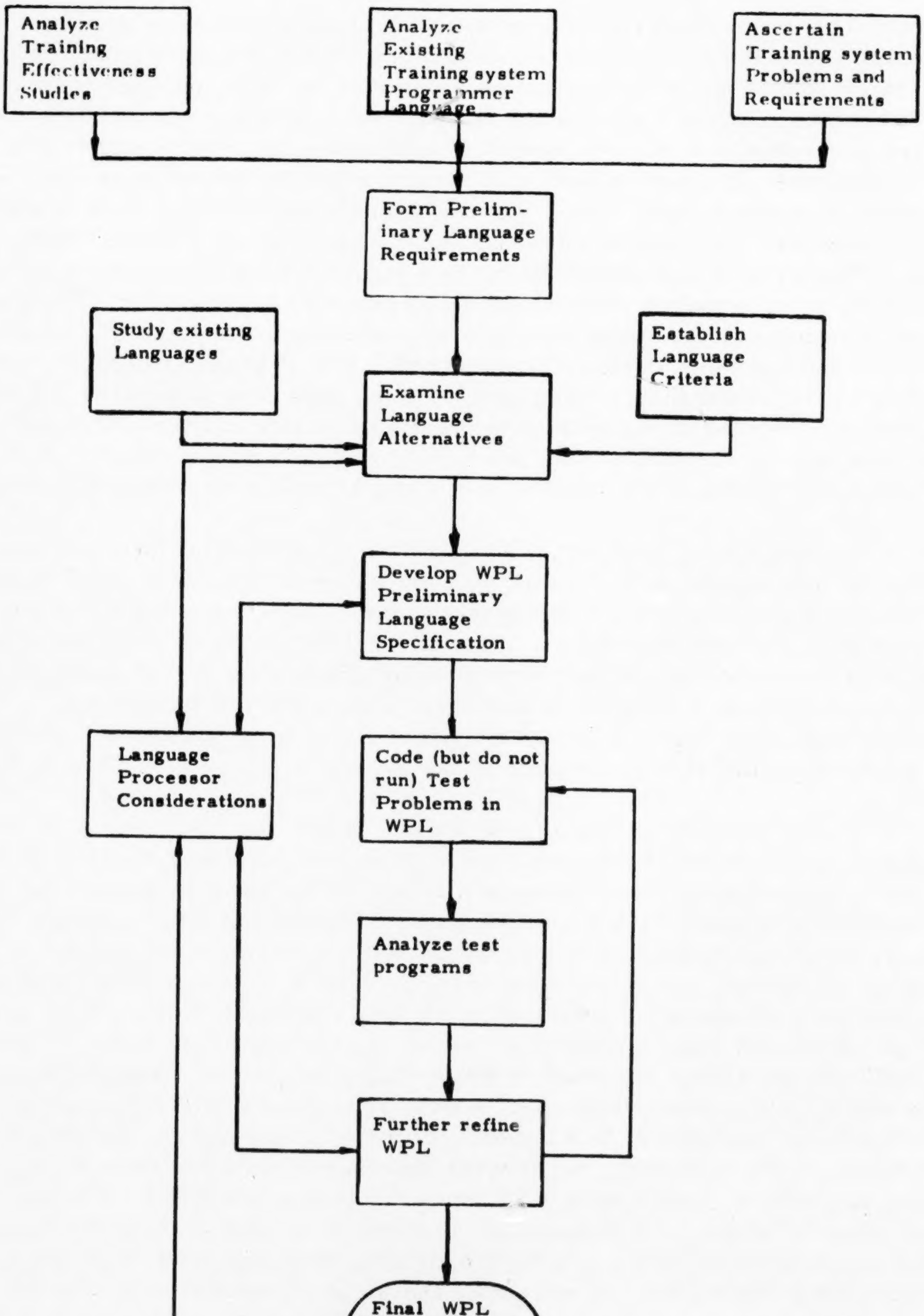
Analyze Training Effectiveness Studies
Analyze Existing Training system Programmer Language
Ascertain Training system Problems and Requirements
Form Preliminary Language Requirements
Study existing Languages
Establish Language Criteria
Examine Language Alternatives
Develop WPL Preliminary Language Specification
Language Processor Considerations
Code (but do not run) Test Problems in WPL
Analyze test programs
Further refine WPL
Final WPL Language Spec. and Processor Requirements

Figure 43. Program language description and task sequence. (from Leonard, Doe & Hofer, 1969)

come about without many false starts. Thus, the first cut training program can be expected to have mistaken assumptions about trainee learning capabilities and problems. A workable, completely automatic training program must be flexible and contain techniques for rapidly altering that program once built."

"The WST Programing Language (WPL) discussed in this report would provide the training technologist with a tool for specifying and altering training approaches in a rapid, flexible manner. WPL could be an immense aid to creating the kind of troubleshooting and performance-criteria-development capabilities that are required in a truly automatic system." (p. 173.)

A study by Vreuls and Obermayer (1970) examined the feasibility of developing methods and measures to satisfy requirements for an automated weapon system trainer. The goal was to establish the state-of-the-art in measurement upon which the development of an automated adaptive trainer may be based. An F-4 type aircraft weapon system (pilot and radar intercept officer) was selected and the air-to-air intercept portion of the primary mission was examined. Three adaptive variables were employed: two task loading stressors (turbulence and time pacing of verbal commands); and one variable which changed the response characteristics of the vehicle (center of gravity). For the two task loading variables, the same measurement set, with slight tolerance changes, was generally adequate. The center of gravity variable required a modified measurement set. While both pilot and RIO measures were developed as well as measures for crew system performance, the greatest effort was devoted to the pilot sets, hence we will emphasize these.

Table 29 shows the suggested performance measures for task dimensions grouped according to aircraft axis systems. An empirical test of the pilot performance measurement candidates for a subset of the pilot task during intercept yielded the performance measures shown in Table 30.

The relationships between adaptive variables and measures were mixed and varied. An examination of the effects of the adaptive variables, one measure at a time, revealed many non-monotonic functions and reversals in trend. Some adaptive variables caused performance to improve on one task, yet deteriorate on another task. For example, increasing the command pacing from 15 seconds to 5 seconds caused roll average error to reduce for the 60° bank but increase for the 30° bank. The results and discussion of the experiments are too voluminous to include here and the relationships are best understood when read in the context of the report. In essence, the recommended measurement sets for turbulence and command pacing adaptive variables and for the center of gravity adaptive variable are shown in Tables 31 and 32, respectively.

TABLE 29. MEASURE CANDIDATES FOR PILOT SYSTEM PERFORMANCE DURING INTERCEPT

AIRCRAFT AXIS SYSTEM	TASK DIMENSION	MEASURE	TREATMENT OR DERIVATION	TOLERANCE	COMMENT
N/A	TARGET DETECTION	Detection Time $P_{(Det)}$ $P_{(FA)}$	Time to detect % Detections % Incorrect Identification	No Data	All detection measures should be based on opportunity of detection
LONGITUDINAL	COMMAND DETECTION	Response Time from verbal command to change in altitude or airspeed	Altitude Rate (500 FPM Change)	1.0-sec.	For Climb Commands
			Airspeed (10 Knot Change)	5.0-sec.	For Speed Commands
		REVERSALS	IC < Value when Response Detected <	CMD-	For either of above Value when response detected should be between the initial value (IC) and the commanded value (CMD)
		or	IC > Value when Response Detected >	CMD-	
	COMMAND ACHIEVED	Airspeed	Rise time between command detection and command achieved	Function of time x thrust + drag ratio Altitude Rate	For Speed commands value has yet to be
		Altitude Rate	Rise time	5-seconds	For altitude rate cmds

TABLE 29. MEASURE CANDIDATES FOR PILOT SYSTEM PERFORMANCE DURING INTERCEPT (Cont.d)

AIRCRAFT AXIS SYSTEM	TASK DIMENSION	MEASURE	TREATMENT OR DERIVATION	TOLERANCE	COMMENT
		Altitude	Rise time	Function of time x altitude required x drag index x gross weight	For altitude commands
	VARIABILITY	Altitude Rate Variability or	Standard Deviation	1000 Fpm	Measure within steady-state portions of profile.
		Alpha Variability	Standard Deviation	1.5 units	Best measure needs empirical determination
	STABILITY	Alpha Damping Ratio	Ratio of successive oscillatory peaks followable command achievement	.95	Variability measures may in part reflect undampened performance
	ACCURACY	Altitude	Error from Command	±200 Feet	For altitude Commands
		Altitude Rate	Error from Command	±500 FPM	For altitude Rate Commands
		Airspeed	Error from Command	±20 Knots or mach equivalent	For speed Commands
		Throttle Position	Discrete Mil-power max power	-	For gate commands

TABLE 29. MEASURE CANDIDATES FOR PILOT SYSTEM PERFORMANCE DURING INTERCEPT (Cont.d)

AIRCRAFT AXIS SYSTEM	TASK DIMENSION	MEASURE	TREATMENT OR DERIVATION	TOLERANCE	COMMENT
LATERAL-DIRECTIONAL	COMMAND DETECTION	Response time from verbal command to changes in roll attitude	Roll attitude (5-degree change)	1.0 sec.	
		Reversals	IC < Roll angle when change detected < CMD	-	Roll attitude value when response time is detected should be between initial value at command (IC) and commanded value (CMD)
		or	IC > Roll angle when change detected > CMD	-	
	COMMAND ACHIEVED	Roll	Rise time	5 seconds	For bank commands
	VARIABILITY	Turn rate Variability	Standard Deviation	.4 deg./sec.	Measure within any steady-state (constant turn or heading) portion of profile
	STABILITY	Roll or turn rate damping ratio	Ratio of successive oscillatory peaks following command achievement	.95	Variability measures may reflect undampened performance

TABLE 29. MEASURE CANDIDATE FOR PILOT SYSTEM PERFORMANCE DURING INTERCEPT (Cont.d)

AIRCRAFT AXIS SYSTEM	TASK DIMENSION	MEASURE	TREATMENT OR DERIVATION	TOLERANCE	COMMENT
	ACCURACY	Roll angle	Error from command	± 5-deg.	For roll commands
		Heading	Error from command	± 5-deg.	For heading commands
		Turn rate	Error from equivalent turn rate for roll command	± .4 deg./sec.	Alternate measure for roll commands
BOTH	COORDINATES (cross-coupling)	g-error	Error from ideal g's for roll command	± .2-g.	
	ENERGY LEVEL	Energy Level and/or rate of change of Energy Level	$E= 1/2\ mv^2 + mh\ 4\ \text{fuel}$	Unknown	Research with this task, and criteria needs to be undertaken.

(from Vreuls and Obermayer, 1970)

TABLE 30. PERFORMANCE MEASURES

PARAMETER	MEASURE	UNITS	ACCURACY
Altitude[1]	Alt Mean	Feet	1. Foot
	Alt Std Dev	Feet	1. Foot
	Alt Range	Feet	1. Foot
Altitude Rate	Alt Rate Mean	Feet/Minute	1. Foot/Min
	Alt Rate Std Dev	Feet/Minute	1. Ft./min
	Alt Rate Range	Feet/Minute	1. Ft./min
True Air Speed[2]	KTAS Mean	Knots	1. Knot
	KTAS Std Dev	Knots	1. Knot
Normal Acceleration	g Mean	G Units	0.1 G
	g Std	G Units	0.1 G
Angle of Attack	Alpha Mean	Alpha Units	0.1 Units
	Alpha Std	Alpha Units	0.1 Units
Roll Rate	Roll Rate Max	Degrees/Second	1. Deg/Sec
Roll Attitude	Roll AE (Average Error)	Degrees	0.1 Degrees
	Roll Std Dev	Degrees	0.1 Degrees
	Roll Response	Seconds	0.2 Seconds
	Roll Rise Time	Seconds	0.2 Seconds
	Roll OAMP (Overshoot Amplitude)	Degrees	0.1 Degrees
	Roll OTIM (Overshoot Time)	Seconds	0.2 Seconds
	Roll Damping Ratio	Ratio	0.1
	Roll Period	Seconds	0.2 Seconds
	Roll Command Achieved	Binary	0

TABLE 30. PERFORMANCE MEASURES (Continued)

PARAMETERS	MEASURE	UNITS	ACCURACY
Inertial Turn Rate	Turn Rate AE	Degrees/Second	0.1 Deg/Sec
	Turn Rate Std	Degrees/Second	0.1 Deg/Sec
	Turn Rate Resp	Seconds	0.2 Seconds
	Turn Rate Rise	Seconds	0.2 Seconds
	Turn Rate OAMP	Degrees	0.1 Degrees
	Turn Rate OTIM	Seconds	0.2 Seconds
	Turn Rate Damp	Ratio	0.1
	Turn Rate Period	Seconds	0.2 Seconds

[1] Reported altitude is the difference between actual altitude and the commanded 25,000 feet.

[2] Reported airspeed is the difference between 532 Knots (Mach .9 at 25,000 feet) and the actual.

(from Vreuls and Obermayer, 1970)

TABLE 31. MEASUREMENT CANDIDATES FOR TURBULENCE AND PACING ADAPTIVE VARIABLES

MEASURE	FUNCTION OF	TOLERANCE
Altitude Error	Altitude Command	±100 Ft.
Altitude Rate Variability	Steady-State Climb/ Dive or Hold Command	±600 Ft./Minute
True Airspeed or IAS or Mach	Steady-State Airspeed Command	±20 knots or mach
Roll Average Error[1]	Bank Command	±5°
g-Error[1,2]	Bank Command	±.2 g for Pacing, ±.4 g for Turbulence
Turn Rate Error[1]	Bank Command	±.2 deg./sec. for Pacing

[1] These measures to be taken from the time a command is first achieved.

[2] g-mean shown on graphs; g-error is the difference between the obtained value and the desired value.

(from Vreuls and Obermayer, 1970)

TABLE 32. MEASUREMENT CANDIDATES FOR C.G.
AS AN ADAPTIVE VARIABLE[1]

MEASURE	FUNCTION OF	TOLERANCE
Altitude Error	Altitude Command	±100 Ft.
Altitude Rate Variability	Steady-State Climb/ Dive or Hold Altitude	±600 Ft.
True Airspeed, or Mach	Steady-State Airspeed Command	±20 knots or equivalent Mach
Roll Overshoot[2] Amplitude	Bank Command	±8 degrees
Alpha Variability[2]	Any Steady State Conditions	±1.5 units
g-error [2,3]	Bank Command	±.4 g
Turn Rate Error[2]	Bank Command	±.4 deg./sec.
Turn Rate Period[2]	C.G. Configuration	±.2 sec.

[1] Measurement list is based on inference from both studies. It is urged that this list be considered tentative until further analysis of the effects of C.G. can be studied.

[2] Measure to be taken from the time command is first achieved.

[3] g-mean is shown; g-error is the difference between the value obtained and the desired value.

(from Vreuls and Obermayer, 1970)

The authors conclude that the specific measures for the pilot (and the RIO and total system which are not shown here) may be used for adaptive training. These represent the best recommendations at this time. "One of the principal conclusions of this study is that measurement for adaptive automated training in a complex weapon system trainer is feasible even though a number of fears and cautions have been given in this report. While the measurement state-of-the-art will not permit the design of such a trainer without some empirical testing, current methods will permit design of a system which operates on a complex description of performance of individual, team and system outputs. On the other hand, other design considerations of automated adaptive trainer design, in particular the adaptive logic, may be somewhat constrained by the characteristics of the performance measurement which is now possible to implement.

In short, the current study effort leads to the conclusion that the development of an automated adaptive weapon system for high-performance aircraft is feasible insofar as design considerations of performance and criterion measures are concerned. Nevertheless, the development of such a trainer will require extensive directed analytic and empirical effort, which can now be identified, to produce a successful product." (Vreuls and Obermayer (1970), p. 166.)

3.5.5 Research Issues. It is difficult to reject the fact that the effectiveness of training is dependent on the effectiveness of measurement, yet, performance scoring is not a strong feature in current training simulators. The measurement studies in the training context are relatively sparse and quite speculative and the research accomplished to develop the measurement capability has principally yielded only requirements and feasibility demonstrations in support of measurement systems for training.

Thus, the prime research requirement continues to be the development of an adequate and objective measurement capability that is intrinsic to classes of training devices. Much emphasis must be accorded to this development, particularly to the automated monitoring, evaluation and scoring in training devices. Some research issues of priority are identified below.

a. The design issues involved in an automated monitoring, evaluation and scoring capability must be systematically explored and guidelines for design developed.

- Work should continue on the psychometric analysis of measurement characteristics including: what measures to obtain relative to classes of training devices; the validity and reliability of proposed measures; whether variability, central tendency or reliability should constitute part of the performance measure (i.e., for automatic adaptive scoring); the reliability of types of scores as measures (e.g., time-in-tolerance scoring); the meaning of in-tolerance scoring for manual control (e.g., is valuable performance information unavailable during the in-tolerance periods?); and the like.

- Data should be organized on sampling intervals for measurement. This includes optimum intervals for sampling and averaging performance, how often should sampling be conducted, and when (in the maneuver/mission context) is sampling most profitably employed. For example, fifty scorings for a given aerial maneuver may be unwieldy and unnecessary, but what is the number desired?

- The development of guidelines for the organization of obtained quantitative information requires a concerted study effort. This includes, the appropriateness of single summary scores, the combination of scores, weighting, ranking of scores, etc. To this end, a systematic effort should be devoted to determining correlations among alternative measures and how various scores are optimally combined.

b. Establishing good criteria for evaluating the effectiveness of training continues to be a considerable requirement. An intriguing research issue is the development of techniques for correlating expert opinions with the quantitative findings from research. This suggests the development of models for identifying performance scores that correlate highly with subjective evaluations of expert instructors.

c. A specific study of immediate utility is the development of measurement systems for non-aviation training devices. The most obvious candidate is the tactical team training device. To date, the measurement capability has not been an integral part of the design of surface or subsurface team trainers, and performance assessment has, for the most part, been accomplished during the post-mission critique session based on instructor judgments about performance.

d. Research is needed on determining the formatting requirements for trainee performance information displayed or recorded at the instructor station. This is particularly important in training situations where student to instructor ratios are high, and involves the information requirements displayed on computer-generated cathode ray tubes and the information requirements for hard-copy printout records for critique and record-keeping purposes. Of concern is the organization of the performance information (error, monitoring information) and what classes of information and specific data to display. The research must consider CRT page format requirements including the display of increasingly specific information by means of successive CRT pagination and formatting. Similar requirements must be satisfied for hard-copy printouts of performance records for critique (to be used both during and at completion of the training exercise) and for school record-keeping purposes (normative data).

e. A limited effort is recommended to examine the extent of student involvement in simulator training. This could involve determining the correlation of physiological indices with performance in simulators to obtain information on the desirability of including human physiological monitoring equipment in training devices (preferably, flight simulators). For example, in the flight context, such equipment may be used to obtain information for assessing the extent to which simulation training induces "pilot involvement" during defined (syllabus) simulator sorties. The question of importance is, how successful is the simulator in representing the critical conditions of flight based on how the pilot is "involved," "aroused," "mobilized" during simulator training. The objective is to understand the extent of pilot involvement (coping behavior) for defined simulator tasks as one means for improving the utilization of flight simulators. The measures of involvement could include:

- Physiological measures (extent of physiological changes with such indicants as heart rate, muscle tenseness, respiratory rate, pupil size, etc.)
- Coping with contingencies (e.g., stereotyped responses, inappropriate response/interference, frequency of response, anticipation, etc.

f. A research area of some significance for design concerns the automation of instructor functions. The issues concern the definition of what functions are best automated and how this is to be accomplished. In essence, the computer should be employed to facilitate rational decisions about training. The values of computer assisted instruction (CAI) in simulator training should be thoroughly explored. The focal points involve computer adjustment of the training material presented to the student based on how he is responding (our present concept of automated adaptive training is exactly this), and computer assists for providing the instructor with information needed for developing optimum strategies for training individual students or teams.

3.6 ADAPTIVE TRAINING STRATEGIES.

A recent innovation for structuring and controlling training in simulators is adaptive simulation. This technique is essentially a model for programing the computer to achieve strategies for effective instruction.

Adaptive training as considered here is restricted to computer-controlled automation of the instructor function in the synthetic training system (i.e., a closed loop machine-controlled feedback system). The technique provides for the automatic variation of the task complexity or difficulty as a consequence of how well the trainee is performing, that is, the training task automatically becomes more difficult as the trainee becomes more skilled (Kelley, 1969). Thus, in adaptive training, task difficulty is automatically kept appropriate to each trainee's level of skill, that is, the level of task difficulty is automatically adjusted to the trainee's momentary level of skill; as he progressively acquires skill, the task becomes increasingly more difficult.

Adaptive training is applicable to any man-operated vehicle simulator as well as to other training situations. The emphasis is on the machine or computer control in the development of a training strategy whereby the difficulty level of the training task is automatically adjusted as a consequence of the immediately preceding performance of the trainee. The feature, "automatic" is emphasized in contradistinction to the usual training situation which strives to achieve an optimum progression in learning based on an instructor controlled sequencing strategy. A distinction can also be made between automatic adaptive sequencing (which is the topic of this chapter) and manual (normal) adaptive sequencing (which involves instructor-developed training strategies based on a number of automated equipment assists). The term, manual adaptive, may legitimately describe a simulated situation whereby an instructor with equipment assists decides on a strategy and initiates a sequencing of training, based on displayed trainee performance information to accommodate each trainee's capability to learn. The intent is to keep each trainee progressing at his own achievement speed (ideally at the threshold of his capability at any given time) so that the task is neither too easy or too difficult.

These assists provide instructional flexibility in employing a simulator for training and unburden the instructor from the more clerical duties in the management of training. As such, this describes a semi-automated instructional capability based on the following:

- Preprogramed, standardized mission scenarios.
- Computer automated measurement and scoring system.
- Computer-driven CRT displays at the instructor console for presenting all relevant performance and mission information in defined operating modes.

- Controls to initiate, continue or modify the preprogramed mission events to achieve a pertinent strategy for each student.

- Hard copy printouts of student performance information for use during and after a mission (critique and school records).

By these means the instructor is able to formalize a decision logic tailored to the trainee based on a responsive monitoring, evaluation and scoring capability.

3.6.1 Differences in Concept. Variations exist in conceptualizing machine-controlled adaptive simulation. The adaptive system developed by Birmingham (1959) simplified an automatic tracking system by adding derivatives of error into the display signal (quickening). The display augmentation is governed by the adaptive circuit so that with poor tracking performance, the trainee is provided help via the display augmenter (see Figure 44). This help is lessened as performance increases until it is removed as the preset criterion is reached. Thus, as performance improves the adaptive variable changes with it, i.e., performance and the adaptive variable change simultaneously.

The technique developed by Kelley (1963) involves averaging a measurement of the subject's performance over a period of time rather than using an instantaneous value of error (as did Birmingham). The average score is used to adjust automatically certain parameters of the task. The scoring technique for use with continuously distributed error scores involves setting an error threshold which is an amount of error that will not produce any change in the system. Error in excess of the threshold results in changes which makes the system easier, while smaller errors cause the system to become more difficult.

Hudson's technique (1964)[1] is similar to Birmingham's in that as the error is decreased, the simulation parameter that is adjusted changes in some fixed relation as a function of improved performance. Thus, the parameter of display quickening is changed in proportion to an average or filtered error score. In Kelley's technique, error is held constant and system difficulty changes are adjusted until the set amount of error is present.

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[1] Also, Hudson, E.M. An Adaptive Tracking Simulator. Paper presented at the IRE International Congress on Human Factors in Electronics, Long Beach, California, 3-4 May 1962.

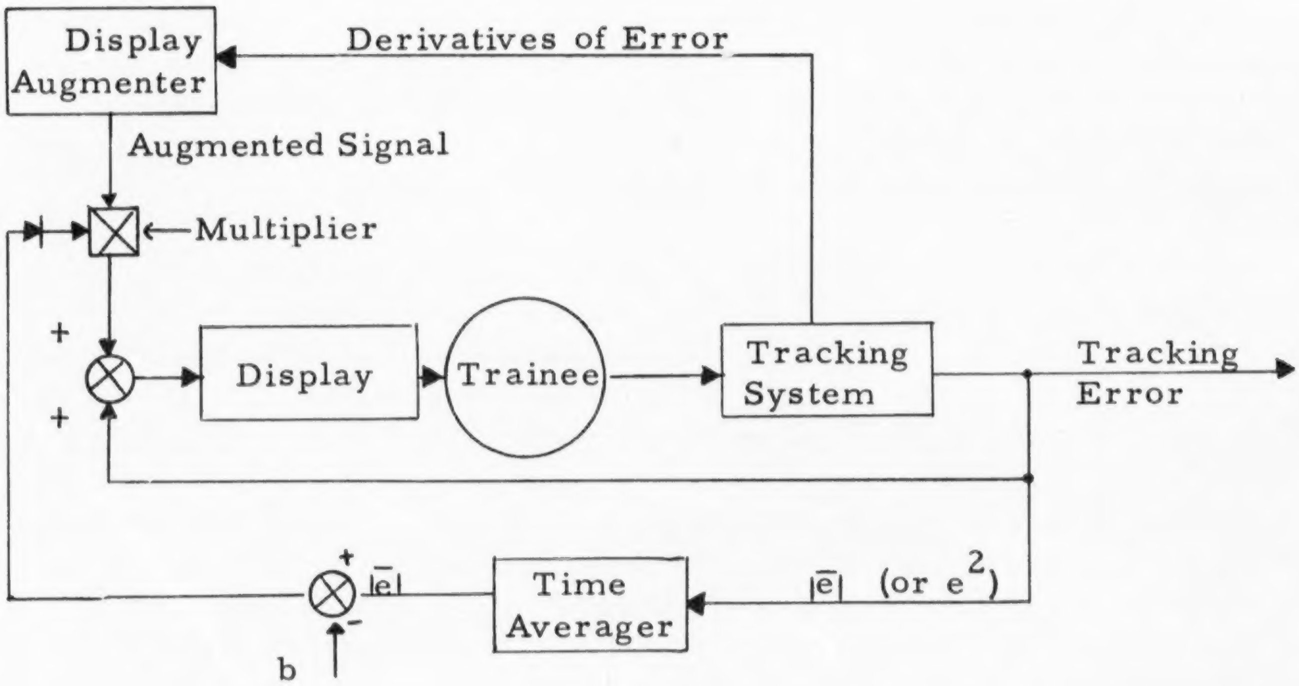
Display Augmenter
Derivatives of Error
Augmented Signal
Multiplier
+
+
Display
Trainee
Tracking System
Tracking Error
+
-
$|\bar{e}|$
Time Averager
$|\bar{e}|$ (or e^2)
b

Figure 44. Early Adaptive System.
(from Kelley, 1969)

The difference in techniques is summarized in the following (Kelley, 1969). In the Birmingham and in the Hudson techniques,

$$y = ax - b$$

in the Kelley technique

$$\frac{dy}{dt} = ax - b$$

where:

y = adaptive variable
x = performance measurement
a and b = constants.

In the first equation, as skill increases, average tracking error decreases, and this decrease brings about an adaptive change in the system. The system adapts as the average error is reduced. In the second equation, average tracking error does not change as skill improves. When the error deviates from the preset standard the system changes until the standard amount of error is again present. Consequently, the system becomes more difficult when performance is above the standard. The adaptive variable changes to keep the average tracking error constant.

The difference between the two basic techniques described above resides in the adaptive logic. For Birmingham, performance is changing as the task is changing; for Kelley, the derivative of the performance measure changes in order to maintain a constant performance over a time period (error is used to modify the system to make the task easier or harder for the trainee). The performance score stays the same; changes in the adaptive variable serve as the index of training. Hudson (1969) utilizes error to modify the system so that it will converge quickly on a value that will reduce error to a minimum, i.e., the system (machine) is modified to more closely match the human's performance. Hudson cites the similarity of his approach to that of sequential analysis where the number of experiments to be conducted is determined during the course of experimentation as a function of the level of significance obtained.

3.6.2 Adaptive Simulation as a Design Option. Perhaps the significant question for design concerns the efficacy of adaptive simulation for training. Does adaptive sequencing enable the trainee to achieve desired proficiency levels more quickly than when conventional means are employed? Unfortunately, no empirical evidence exists at this time that adaptive simulation trains better. Adaptive techniques have served as a research tool and a number of interesting relationships have been demonstrated. But assessments are not available which evaluate the effectiveness of adaptive simulation as a practical training method for producing the skills required in the operational environment. The major difficulty resides in problems associated with the conceptualization and definition of adaptive variables and difficulties in the measurement of performance. These issues are discussed subsequently in this Chapter.

Since evidence is lacking on the training advantages of adaptive sequencing in relation to other training concepts, just what are the perceived positive expectations from its use? Obviously, it is not difficult to favor adaptive training as a concept since logically all training is (ideally) adaptive. Hence, many theoretical advantages inhere in adaptive simulation. As a technique for presenting information to the trainee it has made explicit a number of features that are intuitively desirable. These include the following:

- Formal structure and control of training requiring a deliberate logic (tailoring learning to the individual based on rational decisions about performance)

- Precise control of task loading.

- Objective adjustment of the difficulty level of tasks.

- Structuring the link between the trainee's performance and the presented task.

- Emphasis on measurement during the training process.

- Requirement to analyze all the variables that can influence trainee performance and task difficulty.

- Record of the training process.

While these features are not peculiar to adaptive simulation, all are pertinent to the technique.

Assuming the efficacy of adaptive simulation, what training problems are adaptive techniques best suited to solve? This is a relevant question for design, since it appears that not all training will benefit from this approach. To date, it has been applied almost totally to tracking behavior and perceptual motor skills, so much so that it has become a major preoccupation of flight simulation. Recently, a workshop on adaptive training[1] examined the question of, when do you employ adaptive training methods and for what reasons? Excerpts from this workshop which highlight various opinions of the attendees are organized below.

- Adaptive training methods are called for: 1) when the task to be learned is of sufficient difficulty to require a significant (?) amount of time to achieve mastery, 2) when task improvement is a linear or progressive phenomenon, 3) when the training situation lends itself to automated controls, 4) when the subject population can be controlled to the extent necessary, and 5) when the training task bears sufficient resemblance to the final behavioral model to have a reasonable transfer value.

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[1] Workshop on Adaptive Training, 27-28 April 1970, Institute of Aviation, University of Illinois, Urbana, Illinois.

- The availability of a performance measure, an adaptive variable, and an adaptive logic are the conditions for the use of adaptive training, but of course this is not a reason for its use. Automated adaptive training may be used for the purposes of reducing the need for human instructors, standardizing training procedures, making the decision function more objective and rational, or achieving greater precision of control in presenting tasks and instructional materials. These are important goals, but they can be met by other methods of automated, structured, or programed training that are not necessarily adaptive. The purposes that can be served uniquely by adaptive training must be those which are served by maintaining a continuously closed loop between the student's performance output and the task-stimuli input. Nobody truly knows what clear benefits are offered by adaptive training and only by adaptive training. Every potential benefit of adaptive training that can be suggested as being unique to this technique is properly a hypothesis that requires empirical testing.

- Adaptive training methods are called for when training is already adaptive, but instructor controlled, and when it is desirable for reasons of cost, standardization, or (when it can be demonstrated) training effectiveness to mechanize the instructor's adaptive function. These methods are also appropriate when it can be shown that training time is significantly reduced or that a higher level of skill is reached in the same time by replacing a fixed with an adaptive training schedule. The criterion should be cost-effectiveness, broadly interpreted and applied.

- Adaptive training systems are probably most useful in situations requiring considerable overlearning and high retention over time. They are most appropriate in systems where variables can be closely, perhaps infinitely, controlled; but application to part-task/whole-task grouped learning patterns may not be amenable to the close control over levels of difficulty that seems essential to the technique. The important problem is the relevance of the adaptive variable used as a forcing function (turbulence, for example) to the task for which the student is being trained.

- Adaptive training techniques are justifiable whenever the goal is to automate the training situation, i.e., to replace the instructor with a machine. A good instructor utilizes adaptive techniques in that he tailors the training situation to the individual trainee. The primary problem is to formalize the decision logic in the automated device. This approach, hopefully, will allow at least a standardization, and perhaps an optimization of the training situation.

- Adaptive training requires specification of a decision model which relates observed or measured performance to task difficulty or complexity. In the real-world model, i.e., a human instructor working with a single trainee, decisions are often made on the basis of the instructor's subjective evaluation of trainee performance, and his decision model is not wholly rational. By removing the instructor, a wholly rational decision model can be substituted for him. Intuitively, we can assume that adaptive training then has at least the potential of improving upon the real-world model.

- Adaptive training is called for when the computer can substitute for the instructor and when the task is of such a high order of difficulty that it cannot be mastered unless it is broken down into component parts. What is needed for implementation is an analysis of the task(s) to be trained and then the development of a "strategy" for teaching it.

- The development of adaptive training methods is linked to the goal of automating many instructor functions (in flight simulator training, for example). One reason for doing this is not to replace the instructor, but to relieve him of time-consuming routine duties, so he can use his teaching skills more effectively. It is impossible or impractical to automate some instructor functions, so let's not talk of "getting rid of him."

- Adaptive training methods are most probably called for in perceptual-motor tasks that are too difficult for someone to handle at the outset, such as the task of controlling a helicopter. But, generally, the systems approach must be taken to identifying training applications, using behavioral objectives and task analyses. If a need for adaptive training shows up, then use it. But, it is a mistake to work in the other direction, starting with the assumption that adaptive techniques will be used and then trying to fit them into the program.

3.6.3 The Elements of Adaptive Simulation. A number of issues must be considered in the decision to implement an adaptive simulation capability in a training device. These are subsumed under the key design features of adaptive simulation, specifically: the selection of the adaptive variable(s); the performance measurement technique; the adaptive logic for adjusting task changes; and some display of performance information to the trainee. Design issues within each of those elements are discussed next.

3.6.3.1 Selecting Adaptive Variables. An initial decision is the choice of the parameter or variable which will be manipulated to adjust task difficulty. The task must be scalable along some dimension of graduated difficulty, either continuously or in step fashion. The adaptive variable selected must systematically affect the difficulty of the task.

A number of criteria have been specified for a relevant adaptive variable. Matheny and Norman (1969), for example, have listed the following requirements for the selection of an adaptive variable:

- It must be capable of being described and quantified. That is, it must be capable of being measured.

- It must be related to task difficulty. That is, changes in the adaptive variable must bring about changes in level of performance.

- It must be capable of being varied in a systematic way. Although this seems obvious, in a practical situation, it may not be easy to do.

- When used in devices for training for transfer to a different system, it should not inhibit or interfere with transfer of training. Parenthetically, the addition of the adaptive training feature to a training task which has no training value in and of itself cannot be expected, magically, to endow that task with positive transfer characteristics.

- It must be capable of being adjusted over a range commensurate with the trainee's skill both in increasing and decreasing difficulty. For example, the use of turbulence as an adaptive variable might be limited in its application because in some systems, of which the helicopter may be an example, the task difficulty for the beginning student must be reduced to some level below that of normal operation in calm air. That is, for the beginner, the task may need to be made easier than it actually is in the real system for most efficient training.

- If possible, it must be realistic in the sense that it varies in ways in which the real task varies so that it is acceptable to the trainee. That is to say that it must not change the basic task so that it becomes strange and unreal to the trainee and not acceptable to him as a training situation.

The participants in the recent workshop on adaptive training[1] considered the proper guidelines for selecting adaptive variables. Excerpts from the comments made are cited below.

- The paramount rule should be to select an adaptive variable that is clearly relevant to the operational task being trained. No other guideline matters if this one is violated. The other guidelines mainly insure that the selected variable is practicable. That is, the variations should be easily definable or measurable; the variations should have a significant, reliable, and known effect on the performance requirements; and that effect should be direct and uncomplicated.

- Adaptive variables should be selected in accordance with these guidelines: its variation should be along dimensions relevant to the skill to be taught; its variation should be closely related to measured performance so that it reliably changes measured performance, and it should be convenient to implement.

- The most important guidelines are: the relevance of the forcing function to the skill trained, the ease of varying task difficulty level, and the nature of difficulty dimension itself--that is, whether the difficulty is increased by attention-dividing (bells, lights), a physical challenge (turbulence), or a design change (display size, control dynamics).

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[1] Op. cit., Workshop on Adaptive Training, University of Illinois.

- The following ingredients should be included in any set of guidelines for selecting adaptive variables: 1) sensitivity to the generation of errors regardless of what criteria are employed, 2) possibility and practicality of adjustment in terms of stability and resemblance to the real world, and 3) predictability on the basis of some plausible theory.

- Guidelines required for selecting adaptive variables for training applications may differ from those required to select adaptive variables for research purposes. For training applications, the adaptive variables must be measurable and must be related to progress toward the training objective; that is, the task being trained, the appropriate performance measures, and so on, must be well defined before attempting to select the adaptive variable. For research purposes the adaptive variable must, again, be measurable; however, it must also be adjustable over a relatively wide range of skill levels, with particularly good coverage at the lower end of the continuum.

- It seems clear that the adaptive variable must do no obvious violence to the training situation.

3.6.3.1.1 Classes of Adaptive Variables. Not much data exist on the possible adaptive variables relevant for classes of training tasks. There are, however, rational choices that may be made of adaptive variables that seem potentially useful in producing the required realism in the training task. These appear to meet the criteria set forth earlier. For example, Kelley and Wargo (1968) have cited the following task aspects that can be changed adaptively.

- The simulated environment may be changed (e.g., illumination, sound level, temperature, or simulated gustiness or turbulence may be varied).

- Stress applied to the operator can be varied (e.g., g-forces, vibration, oxygen pressure, drugs).

- The controlled element (simulated vehicle) can be modified (e.g., by varying the gain of a stability augmenting signal).

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- The operator's control can be varied (e.g., by adjusting its gain, simulated feel, or backlash).
- Displays can be varied (e.g., by changing the gain, lag, amount of "quickening" of a quickened display, or prediction span of a predictor display).
- Problem generation may result in harder or easier command trajectories to follow, maneuvers to perform, etc. This includes the important training application of progression through a graded sequence of tasks or problems.
- Secondary task loading on the operator may be changed adaptively, adjusting, for example, the communication load, or the fluctuations in engine instruments requiring monitoring and adjustment.

Our discussion of the classes of adaptive variables tacitly assumes the rejoinder that the surety of selection awaits more empirical evidence. Within each of the classes of adaptive variable there is a variety of simulator features that can be varied, so that these singly or in combination provide a substantial range of possibilities. Since experience with adaptive simulation is meager, it is well to consider only a single continuum of difficulty for design. At present, the interactions among multiple dimensions are not well understood, hence complex scoring schemes are not encouraged without further research. The classes of adaptive variables relevant to training design are described next.

a. External Forcing Function--turbulence has been most investigated as an adaptive variable in flight simulation, employed to make the control task more difficult. Obviously, its use at the outset of training is limited. Also, in systems difficult to control because of systems dynamics, difficulty level cannot be decreased below the level set by the system dynamics, hence, turbulence may not be a prime choice. In defining the turbulence spectrum, decisions involve variations in frequency, amplitude or both. Bandwidth of the forcing function appears critical in that it may interact with rate of change in difficulty and the length of the interval during which performance is measured (Lowes, et al, 1968). Wind velocity (head wind or tail wind) appears useful in that increases or decreases in ground speed influence difficulty level in terms of time constraints. Crosswinds have the effect of increasing the workload for the trainee in ground tracking since aircraft headings must consider this wind vector.

b. Vehicle Characteristics-- several types of difficulty factors have been identified as promising for manipulating task complexity. These include:

- Control damping--increasing the moment of inertia on the control motions can be used to make the task less difficult. With damping, the trainee is not required to respond as quickly as without damping, hence loss of aircraft control, especially during initial training, will be less likely.

- Center of gravity changes--CG shifting resulting from fuel loads may vary the trainee's workload in aircraft control.

- Malfunctions--relevant system malfunctions are pertinent to graduated task difficulty levels.

c. Signal Characteristics--this includes degradation in signal characteristics (e.g., noise); the incidence of signals per unit of time in a mission context (e.g., density of ECM signals of varying priority classes for a given time unit), and simultaneity of signals at a given time (e.g., two or more high priority EW signals as immediate threats in the airborne environment).

d. Secondary Task Loading--the secondary task has been suggested as an adaptive variable, i.e., adjusting the primary task difficulty by secondary task loading. Kelley and Wargo (1967) employed tracking error in the primary task to adjust the loading of a secondary task performed by the subject. Loading was increased or decreased as performance exceeded or fell below a preset standard. In this way, primary task performance was stabilized at the preset standard and all variance in performance due to the independent variable (in this case, different sized tracking displays) was transferred to the loading task scores. This loading task technique (called "cross-adaptive" loading yielded a single new dependent variable which is degree of operator loading). The authors concluded that this was more sensitive to the independent variable than were primary task scores alone or in combination with the secondary task scores.

However, the use of secondary tasks must be considered carefully in training device design, if only from the viewpoint of task changing or realism. Of concern is the issue of whether secondary tasks change task difficulty or actually change the task. For flight training, the variables of communications and command pacing are perceived as realistic, but they may add to task structure more than just increasing the task difficulty. In other words, the object is not to just increase difficulty but also to make the task more realistic. If the secondary task is to be considered as an adaptive variable, then attention must be paid to how the trainee perceives the two tasks, the relative difficulty level of the two tasks, the amount of trainee activity involved in performing both tasks and the manipulation rates for the secondary task. It seems best to argue that the secondary task technique is more useful as a laboratory research tool rather than as an adaptive variable for operational training.

e. System Quickening--Matheny (Matheny and Norman, 1969) has investigated the efficacy of system quickening as an adaptive variable. In system quickening the actual output of the system is changed by the quickening. This is in distinction to display quickening wherein error scores are derived for displayed error rather than for system output. The investigation thus far, however, suggests that quickening and aiding are of relatively low priority as candidates for adaptive variables.

f. Effective Time Constant--Changes in the effective time constant of the vehicle response (t_e), is proposed as an adaptive variable. The effective time constant of the man-machine system is a measure of the time between control input initiation and the operator's detection of the vehicle response to the control input, i.e., the speed with which the operator detects the results of a control movement. It is a measure of the responsiveness of the vehicle to control movements and is made up of the speed of the vehicle response and the operator's threshold for detecting changes resulting from control inputs. Matheny and Norman (1968) showed t_e to be related to rate of learning and to final level of precision of control. Level of performance was related to the interactive effects of t_e and system gain, with the effects of gain most prominent during initial learning and t_e more important in determining final level of performance. For an adaptive training sequence, optimum gain and t_e would be provided in initial training. As training progressed, gain and t_e would be adjusted to achieve the task difficulty progression.

g. Changes in Control Order--Hudson (1964) suggested that changes in control order during training is an important issue; optimum learning may occur when the practice task involves moderate or average level of difficulty regardless of the level of difficulty of the criterion task. Level of training achieved is largely a function of level of difficulty during practice.

3.6.3.2 Measuring Performance. Adaptive measurement technique is relatively new and not much data for design are available. However, obtaining relevant and reliable performance measures is as critical as is the selection of the adaptive variables for training, so much so that the success of adaptive training is predicated on adequate measurement. The research to date has focused on tracking tasks using traditional performance indices (absolute error, time-on-target) as a performance criterion to adjust an adaptive variable affecting the task.

Kelley and Wargo (1968) recommend that performance in vehicle control be measured along several dimensions with a separate standard or criterion of performance established for each dimension. Thus, performance should be measured in each dimension, scored separately and combined into an overall score. The authors have provided an example for satisfying measurement requirements for device 2B24, Synthetic Flight Training System. Possible performance measurements for the training device begin with basic vehicle control parameters--airspeed, altitude, and attitude during steady state flight. Error tolerances for each parameter must be established empirically for various flight conditions. Measurement should also consider task components such as vehicle status monitoring, navigation and communication even though these are more difficult to measure effectively. The scoring of flight path control during maneuvers can be achieved by computing repetitively the response of an "ideal" pilot which is compared to the trainee response on the basis of vehicle output parameters since there is a wide range of operator control manipulations that will result in the desired vehicle response. Instantaneous performance should be measured in terms of basic vehicle state parameters. The parameters suggested are: three coordinates of position; air speed; heading; rate of climb/descent; and pitch (roll and cross-track velocity could be used if found to be important). A nominal value should be computed for each scoring parameter via a computer-based model representing the desired vehicle state at each instant, and recomputed periodically based on new real-time parameters. Error tolerances about the nominal values for each scoring parameter should be established (e.g., four categories ranging from "within tolerance" or "far out-of-tolerance"). An accumulating error score should be kept for each scoring parameter. Scores not in tolerance should be weighted (incremental). Performance on all parameters together should be assessed by logical rules (adaptive logic) to determine if adjustments in task difficulty are warranted. (In determining the adaptive logic, tolerance limit settings and logic rules require examination of score distributions and intercorrelations on tasks performed by skilled pilots).

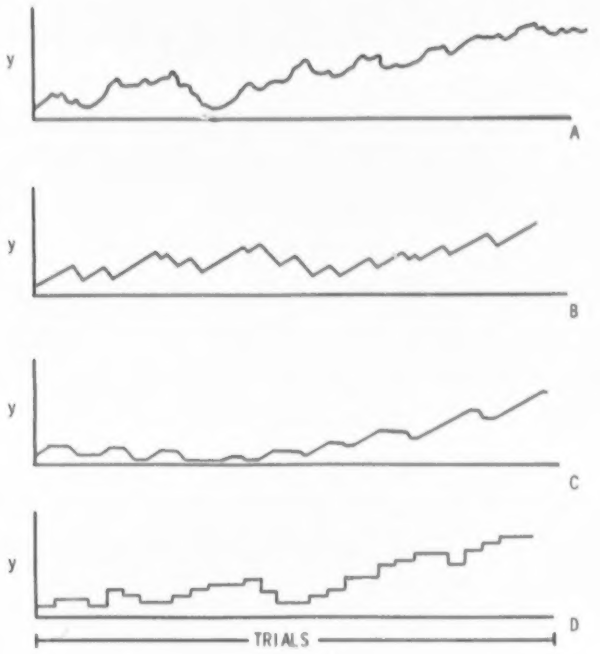
Kelley has indicated, however, that the measurement approach as presently planned for device 2B24 is of doubtful reliability and does not appear to provide effective adaptive task control. This shortcoming, in our opinion, is applicable at present to all adaptive training.

3.6.3.3 Adaptive Logic. A training system is adaptive to the extent that task difficulty level is an automatic function of measured performance (no instructor intervention). The adaptive change occurs as a result of the difference between a preset performance standard and the latest measurement of performance. Thus, the adaptive logic links the adaptive variables and performance measurements. These are the sets of rules (in the form of equations or adjustment rules describing the relationship between measurement and the adaptive variable) for adjusting task difficulty as a function of trainee performance.

Kelley (Kelley and Wargo, 1968; Kelley, 1969) describes typical time histories of an adaptive variable where rate of change is a function of different adaptive equations. Figure 45 shows these adaptive learning curves. Curve A shows a continuously variable rate of change. Whenever the system error is less than the criterion, the trainee is performing above standard and the adaptive score increases, thus the task is made more difficult. When the error is above the standard, the adaptive score decreases and the task is made easier. Curve B shows adaptation limited to one of two fixed rates. When performance is better than the criterion, system difficulty is increased at a fixed rate; when performance is less than the criterion, system difficulty is decreased at another fixed rate. Curve C is similar to curve B, except that there is a central "deadband," or zone in which the system does not change at all. The level portions of the curve indicate those periods in which the subject is performing at close enough to standard that no change in system difficulty is taking place. Curve D shows the course of learning when a system changes by discrete units at fixed intervals of time. This particular system also has a "deadband," so that when measured performance is close to standard, no change takes place in the system. The long segments of the curve occur where the system stays the same for two time periods instead of just one. These indicate periods in which performance was very close to standard. All of the curves indicate successful techniques for implementing adaptive training.

Equations for adaptive logic pertinent to various task requirements have been recommended by Kelley and Wargo (1968). Formulae for achieving an instantaneous level and an average level of adaptive variables are shown below.

Equations for Instantaneous Level of Adaptive Variable	Application
(1) $D = K[(1-A) R - AW] + D_{initial}$, D = the adaptive variable, a higher score representing a more difficult condition K = the sensitivity coefficient determining the size of increments and decrements in D R = number of previous right responses	Tasks in which measured responses are discrete in time and dichotomous or dichotomized in extent. "D" is incremented each trial by one amount or decremented by another. The relative size of an increment vs. a decrement determines the level adapted to. A decrement equal to 9 times the increment will cause adaptation to a level where 1 response in 10 is decremented, i.e., the 90 percent level.



A. $\frac{dy}{dt} = K(X - X_T)$.

B. $\frac{dy}{dt} = K_1$, *when* $X > X_T$; $= K_2$, *when* $X < X_T$.

C. $\frac{dy}{dt} = K_1$, *when* $X > X_1$; $= 0$, *when* $X_1 > X > X_2$;
$= K_2$ *when* $X < X_2$.

D. $y_{i+1} = (y_i + KX)$, *when* $X > X_1$; $= y_i$, *when* $X_1 > X > X_2$; $= (y_i - KX)$ *when* $X < X_2$.
(*i = trial number.*)

Figure 45 . Adaptive Learning Curves.
(from Kelley, 1969)

Equations for Instantaneous Level of Adaptive Variable (Continued)	Application
W = number of previous wrong responses A = the desired proportion of right responses at threshold The desired threshold in percent is equal to 100A.	
(2) $C = K \int_{0}^{T} (c_L - c)dt + C_{initial}$, C = the instantaneous adaptive score adjusting task difficulty, a higher scoring corresponding to better performance and a more difficult task K = the sensitivity coefficient governing the rate of increase or decrease of C c = tracking error, however, that may be defined. It may refer to mean absolute error in a single axis, or to multi axis vector error, to proportion of time on target, etc. c_L=present error threshold; when $c = c_L$, C does not change and the task remains fixed	Tasks in which measured response is continuous in time and in extent, as in tracking and manual control. Adaptation rate is proportional to the difference between desired and actual level of response.
(3) $D = D_{initial} + K \sum_{i=1}^{n} (X_i - X_L)$, D = the adaptive score at the nth measurement K = the sensitivity coefficient determining the amount of change in D per unit difference between X and X_L	Tasks in which measured responses are discrete in time and continuous in extent, the equivalent of (2) for discrete responses. Adaptive level is incremented or decremented each measured response in proportion to the difference between desired and actual level of response.

Equations for Instantaneous Level of Adaptive Variable (Continued) — Application

X_i = each of the n measurements, whether they be individual scores or a running average

X_L = a constant, the preset error threshold or desired value of X

Equations for Average Level of Adaptive Variation

(1a and 3a) $$\overline{D} = \frac{1}{n-r} \sum_{i=r+1}^{n} D_i,$$

D_i = the ith adaptive score, D, figured as of Equation (1) or (3), and

r = the number of settling trials, after which averaging of the adaptive score begins, and

n = the total number of trials or scores, including the settling series, $D_1 - D_r$

Average of the adaptive variable D for discrete responses (Equations (1) and (3)), over an averaging series of n-r responses; taken after a series of r settling responses are made to bring D to approximately the appropriate level.

(2a) $$\overline{C} = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} C \, dt,$$

$\overline{C}$ = the time averaged value of C in Equation 2

T_1 = start of averaging period (end of settling time), and

T_2 = total length of the trial including the settling period of length T_1

Average of the adaptive variable C for continuous response (Equation (2)) over an averaging trial of $T_2 - T_1$ seconds duration; taken after a settling period of T_1 seconds is made to bring C to approximately the appropriate level.

The error standard must be carefully established. The trainee's actual moment-to-moment performance is compared against this criterion and task difficulty level is adjusted as a result of this comparison. Obviously, there is an optimum standard; less than this will degrade training efficiency. When the standard is too tight the error tolerance is small and the adaptive system will automatically remain less difficult to the trainee; when the standard is too loose, the trainee will progress more rapidly to a more difficult task configuration.

Another mistake that can be made in mechanizing the adaptive logic is failing to achieve the optimum in length of the performance sampling periods. When the sampling period is too short, exaggerated changes in difficulty level may occur and task difficulty may exceed the trainee's momentary skill level. Thus, the design decision must consider carefully the implications of slow varying vs. quick varying adaptive tasks, particularly, if large fluctuations in trainee performance are expected, since these may force the system to adjust difficulty level excessively. In this sense, slow varying adaptation represents a more reasonable selection than does quick-varying adaptation.

3.6.3.4 Display of Performance Information. Mention should be made of the feedback of performance information to the trainee since motivation to perform in synthetic training systems is an issue of some concern for design. In essence, the kind of adaptive simulations described earlier does not provide the trainee with any clear evidence of progress. Task closure is not achieved by the trainee since as skill increases so does task difficulty. The experience of improvement is blunted (insufficient task-inherent knowledge of results) and, by definition, complete task mastery cannot be achieved.

The consensus is that supplementary knowledge of results should be displayed, even though artificial and not directly related to the criterion task. Some digital readout of the momentary status of the adaptive variables seems sufficient. Device 2B24, for example, will employ a meter which gives the level of difficulty of the system at each moment. A two-part score is proposed. The first part (2-3 digits) identifies the mission or the problem installed; the second part (1-2 digits) identifies the level of problem difficulty as determined by the intensity of the adaptive variable.

Indicator lights may be used to depict out-of-tolerance conditions as they emerge. Augmented feedback may also be provided directly on a primary display, for example, in the form of an alpha-numeric message alerting the trainee to a specific out-of-tolerance error.

The issue of whether knowledge of performance information should be displayed continuously, periodically or event oriented, and directly or indirectly cannot be resolved at this time. It is, nevertheless, of importance to design.

3.6.4 Adaptive Sequencing in the Synthetic Flight Training System (Device 2B24). The first attempt to include adaptive simulation in a flight trainer is in Device 2B24. This device, designed within the Army's concept of a Synthetic Flight Training System (SFTS), consists of four UH-1 helicopter simulators and associated motion platforms, a general purpose digital computer and an instructor station (Caro, 1969; NTDC, 1968). A design goal has been to provide high fidelity simulation of the helicopter pilot's task and to treat the instructor-simulator combination as a pilot production subsystem. The attempt has been to automate those instructor functions that would enhance system operation. Although Device 2B24 has a number of automated instructional assists, it is not primarily an adaptive training system. At present, the adaptive simulation is a relatively small part of the system, but one that perhaps, over time, will grow.

The selection of adaptive variables began with the Army-imposed restriction that the variables have a plausible relationship to flying so as to encourage task acceptance by the trainees. At present, four adaptive variables have been selected for implementation. These are:

- turbulence (either longitudinal axis or roll axis emphasis)
- control damping (increasing the moment of inertia on the control motions--i.e., airframe response)
- horizontal wind (headwind or tailwind to modify ground speed)
- crosswind

Measurement will consider the important parameters of aircraft control and performance tolerances have been set based on best estimates guided by experience. Table 33 lists the performance tolerances for specified performance parameters. Error scoring for the purpose of adjusting task difficulty will be in percent time out-of-tolerance for each scored parameter. As it now stands, the scores will be treated separately for each parameter rather than being combined into a single score. To increase task difficulty, performance must be within tolerance for a designated percent of the sample time on all parameters being used in a training exercise.

TABLE 33. PERFORMANCE TOLERANCES (DEVICE 2B24)

Performance Parameter	Acceptable Tolerances
Altitude	±100 feet
Airspeed	±10 knots
Heading	±5°
Vertical Speed	±200 fpm
Rate of Turn	±1°/sec
Ball Position	±1/4 ball
Pitch Attitude	±4°
Roll Attitude	±5°
Course Deviation	± 1 dot
Glide Slope Deviation	± 1 dot
Torque Pressure	± 4 psi

The entire task interval has been arbitrarily divided into 10-second intervals, i.e., every 10 seconds, time out-of-tolerance and error rate is examined on each parameter. In the initial programing, error rate may be set at 10 percent. Task difficulty will not change if performance is within tolerance 90% of the time during the sample period. If performance is acceptable less than 90% of the time, task difficulty will decrease; task difficulty will increase if acceptable performance exceeds these limits. The criterion function is reset to zero whenever the difficulty level changes. The magnitude of the adjustment in task difficulty will be a function of the particular adaptive variable being employed in each problem.

Each trainee will receive knowledge of results of progress via a two-part digital readout. The first part indicates the problem being practiced (this would indicate level of difficulty or stage of training if exercises are graduated in difficulty); the second part indicates the level of problem difficulty as determined by the intensity of the adaptive variable. Thus, a score of 18.50 indicates that problem 18 is in effect with a moderate intensity

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level for the adaptive variable being employed (i.e., entry difficulty level of 3; exit criterion difficulty level of 9).

It is emphasized that the above describes initial programing requirements since the device is not expected to be on-line prior to 1971. Thus, adjustments will be made and concepts may be revised through a series of successive approximations until the optimum values are achieved as experience with the on-line device accumulates.

The problems besetting the SFTS in implementing adaptive sequencing have been considered by the recent adaptive training workshop at the University of Illinois.[1] Excerpts from this deliberation are described below.

- The major problem is in the performance measures. The validity and the reliability of the proposed measures can be questioned. Research is recommended using the SFTS, on the performance measurement problem before very much reliance is placed on the adaptive training feature of the system. For example, percent of time-out-of-tolerance may be a useful measure for some of the training but its usefulness is a function of the validity of the tolerances employed.

- The 10-second interval of performance measurement for determining adaptive changes will probably be too short. The available empirical evidence on adaptive training seems to favor the "slowly adapting" system, and so does theory. Moreover, on the grounds of psychophysics alone, there are few aspects of human performance that can be measured reliably in 10 seconds; and if the performance measurement is unreliable, then of course the adaptive "logic" is reduced to a largely random process.

- The time-out-of-tolerance measures of performance may have to be better defined. It is possible that much information of potential value may be lost during the "in-tolerance" performance. In addition, the very complexity of the SFTS model may obscure some of the important factors involved in the adaptive training process.

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[1] Op. cit., Workshop on Adaptive Training, University of Illinois.

- The planned appraoch that calls for the trainee to practice control on one axis, then on two axes, and so on, will lead to difficulties in transfering from one task to another in the sequence. The freezing of any axis or set of axes may cause the trainee to adapt to response modes that are incompatible with response modes required when the axis or axes are unfrozen. This situation could result in significant negative, or at least neutral, transfer from one task to the next.

- A good start has been made on the choice of adaptive variables. Of course, the adaptive logic requires empirical study with a great deal of attention given to the standards employed. The overriding problem in the SFTS implementation, however, is that of performance measurement. There is doubt that the measurement approach presently planned is reliable, or that it will result in effective adaptive task control.

- Early in the SFTS implementation a great deal of refinement is going to have to take place in the exit criteria and in the way a student is tracked through his training. It is anticipated that the 1 to 9 scheme for scaling difficulty will have to be revised and that a system for accumulating milestone "misses" will have to be incorporated. Also, student motivation will probably not be handled very well by the current scheme.

The same workshop on adaptive training cited above considered high priority research requirements for the SFTS. Excerpts of the proposals are listed below.

- The highest priority research should involve the improvement of the adaptive features of the SFTS itself. Although primary attention should go to the problem of performance measurement, both adaptive logic and adaptive variables should be studied. At the next level of priority, the SFTS should be used to explore a broad spectrum of different and more sophisticated areas relating to adaptive training. An example would be diagnostic programing: measuring special complex aspects of performance (pilot-related oscillation, engine instrument monitoring) and using diagnostic measurements for appropriate instruction to remedy the faults or problems diagnosed.

- As a matter of strategy, the first objective should be to accomplish that research which will most enhance the validity of the SFTS for its assigned mission: the training of helicopter pilots. The directors of the SFTS program should resist any immediate temptation to use the SFTS as a general research tool for exploring theoretical issues. The technology of adaptive training would be better served by a mission-oriented research program. When it has been demonstrated that the SFTS works--that it is an effective and practical training system--its versatility can be turned to the purposes of basic research. In other words, SFTS priority should go to the need to solve its own problems. After all, if the SFTS fails, adaptive training as an instructional technique fails, for it is billed (intentionally or not) as the epitome of adaptive training.

- Four research areas are of a high priority. First, the performance measures and performance criteria required to effect the adaptive training feature must be developed and validated. Second, a transfer-of-training study is needed to compare non-automated, instructor-managed training with the SFTS adaptive training concepts. Third, alternative adaptive variables, variables in addition to turbulence and control damping, should be investigated. A particularly interesting possibility would be the use of task structuring by means of various degrees of task loading via malfunction insertion. Finally, research is needed to determine the optimum relationship between the instructor and students in the SFTS. How can the instructor best be kept informed of the progress of the students? Is there an optimum instructor-student ratio?

- An experiment on the most appropriate ways of presenting feedback to the student regarding levels of difficulty is suggested. The following methods of presenting feedback could be evaluated: warning the student concurrently with a change; notifying the student concurrently with a change; notifying the student only after a change in difficulty level has occurred; and providing him no feedback at all. A second series of experiments might compare the simultaneous variation of adaptive variables to their one-at-a-time variation. Finally, the use of the SFTS as a predictor of subsequent pilot performance should be investigated. Measures of performance, or levels of difficulty attained, during early trials may be highly correlated with measures of final performance.

- The initiation of research studies is recommended that would provide the following: proof of the validity of the adaptive techniques, guidelines for the selection of candidate adaptive variables, value of simulation versus flight methods for training; the contribution of major hardware subsystems in simulation; and psychological and engineering data that would be available for study by outside groups.

- The SFTS would be a good vehicle in which to explore how adaptive logic can be applied to the progression or regression from unit to unit within a task element. Such an effort could help answer some of the questions about measurement needs, the criteria to be used, the computer programing, and the hardware requirements in moving from automated demonstration to guided practice to adaptive practice, and back again.

- Parametric studies of all kinds should be conducted. For example, what are the optimal rates of adaptation? Our greatest need right now is for numbers. A related, but independent, problem concerns the efficacy of "adaptive" techniques relative to "non-adaptive" techniques. The SFTS could be the vehicle with which to conduct a full-blown transfer study involving real pilot trainees and real helicopters.

- The highest priority should be given to experimentation involving the following variables: task difficulty increments and decrements, length of the performance sampling periods, types of performance measures, and characteristics of the adaptive logic.

3.6.5 Research Issues. Adaptive sequencing as a technique for programing the computer is a new approach for training device design and not much data are available as guides for design. It is a "wide open" area for research involving many problems and issues to be resolved before design guidelines can be established. At this time, we are unable to use the adaptive technique efficiently in training without research and application in a number of areas. The most prominent research needs reside in selecting adaptive variables, in defining the measurement requirements and in specifying the adaptive logic to be employed.

The issue of the task difficulty continuum for arranging a series of tasks is subject to scrutiny. The formal work to date has been concerned primarily with closed-loop tracking tasks. While adaptive sequencing in terms of difficulty gradations has utility for flight vehicle simulation there are arguments favoring the progression of behavior in training in addition to the variation in task difficulty (easy to difficult task presentation), i.e., the ordering of materials is as important as a difficulty progression in learning. Certain job situations involve the acquisition of a set of skills before additional skills can be mastered, and these may be no more difficult than the preceding set. This is particularly so in cognitive tasks and in verbal learning. The familiar part-task to whole-task learning progression is meaningful here. The idea of the task remaining the same does not effectively handle situations where subtasks are progressively added to the learning situation so that the amount of information learned increases as a prelude to handling other aspects of the job.

The whole issue of performance measurement needs resolution. The validity and reliability of measures for adaptive sequencing must be systematically explored. For vehicle systems, research to date has examined adaptation along a single continuum. Data are not available on systems adapting independently along several dimensions. Research is needed on combining several variables into a single score of performance in which individual criteria and weightings of the components of the combined measurement are established.

Much work is also required to establish data on the length of performance sampling periods and on criterion limits. Loose vs. tight performance tolerances is an issue of some concern in terms of slow-varying vs. quick-varying adaptive tasks. Changes in the adaptive variable must not yield erratic changes in the levels of difficulty.

The specific researchable issues are many and far-reaching concerning the attempt to use adaptive sequencing to advantage in the design of training devices. Those that appear to have priority relative to the application of adaptive simulation to practical training problems are identified next.

a. An initial requirement is to accumulate insights and data on the values of adaptive sequencing for classes of training devices. A legitimate question is, does adaptive training provide better training than does more conventional approaches (in terms of costs/time, transfer of training, retention, acceptance motivation, skill levels/abilities of trainees, etc.). What are the advantages for simulator design? What principles define adaptive training? What constraints are associated with adaptive sequencing? What task situations are most amenable to this approach (i.e., what classes of training device would benefit most)? Is it advantageous to use adaptive and conventional sequencing in day-to-day operational training? These are pertinent considerations. For example, in Kelley's technique, performance is held constant while the task changes in difficulty. In effect, the trainee lacks the opportunity for complete task mastery. What effect does this have on training? Thus, exploratory study is needed to put into perspective the reasonable expectations from the use of adaptive training as a prelude to shaping a meaningful and consistent research effort.

b. The definition and exploration of the relevant classes of adaptive variables should continue as a priority effort. This should involve analyses of the variables that will influence trainee performance or task difficulty. In addition to the variables listed earlier in this Chapter, a number of others seem relevant, for example, alerting cues. Since much of the available research has been devoted to perceptual-motor adaptive models, research is needed on the use of adaptive concepts and the definition of adaptive variables for training situations quite different from aircraft control situations, for example, cognitive skills, verbal learning, and tactical decision-making behavior.

Assessing and equating difficulty levels between adaptive variables is also recommended. This would involve explicit descriptions of difficulty as a function of performance. So far, two opposed techniques have formulated the relationship between difficulty and performance. For Kelley, performance is held constant while the task changes in difficulty; for Birmingham and for Hudson, task difficulty increases as performance increases.

c. The performance measurement requirements are crucial since adaptive training depends on effective measurement. Thus, a primary research goal is the development of automatic performance measurement technology. This includes the development of data on the types of measures needed, the use of single and combined scores for single and multiple task dimensions, weighting requirements, etc. The basic questions are the same: what should be measured, how do you measure, when do you measure, and how do you organize the measurement information? Underlying these are the issues of reliability, validity and sensitivity of the measures.

The selection of performance standards (e.g., RMS, mean absolute error, time-in-tolerance, etc.) for training system design cannot be made on any systematic basis, thus a considerable research effort is indicated here. At the present time, error measurement is of some concern based both on the paucity of design data and on certain concepts of adaptive systems (for example, in Kelley's technique, information on the distribution of error in trainee performance is not available).

d. The adaptive logic requirements are of course another major contributor to the success of adaptive sequencing. A great deal of design data is required on criterion limits for various measures and for stages of training. The dimension of slow varying-quick varying adaptive tasks will influence significantly the orderly progression of adjustments in difficulty level. Changes must correlate well with momentary skill levels. Thus, at issue is the rationale(s) for adjusting task complexity. Design data are needed on performance tolerance envelopes for defined performances, on performance sampling periods, on rates of increase or decrease in difficulty levels on the magnitudes of the adjustment of difficulty, and on the effects of discrete and continuous modes of adjustment of task difficulty. Considerable attention must also be given to the relationships that obtain between the type of adaptive logic and the types of performance measures used.

e. Some attention should be devoted to the design requirements for the display of augmented feedback information to the trainee. Obviously, there is no question about the value of knowledge of results in training, but the issue concerns the kinds of information to present (form) and how this information is best displayed (discretely, time bands, continuously). What are the advantages/disadvantages of inherent vs. artificial feedback in performance? For example, in Kelley's technique, knowledge of results represents an index of how difficult the system is at any given time, rather than an indication of how well the trainee is doing (since the trainee's performance is constant).

3.7 DELIBERATE DEPARTURES FROM REALISM IN DESIGN.

A training simulator, by definition, represents some defined portion of a real situation and provides precise control over and planned variation of the training materials and sequences presented to the trainee. It also permits the deliberate omission of aspects of the operational situation in order to eliminate or reduce: natural variability and unpredictability; hazards; and elements not critical to task performance, not conducive to learning, or evidently not yielding sufficient advantage for the costs involved. A precise correspondence to a real job context is not a prerequisite for transfer of training. There is ample evidence that significant transfer of training accrues not only with low fidelity stimulus and control conditions, but even when there are significant alterations in equipment configurations/operations and/or omissions of secondary cues found in the operational environment.

This Chapter presents concepts and techniques for deliberately departing from realism in design in order to enhance training effectiveness. These refer to planned deviations in configuration or operation associated with the operational system being simulated to aid learning, and thus differ from a cost-effective lowering of the engineering fidelity or a reduction in fidelity tolerances where the engineering state-of-the-art is less than adequate. The intelligent use of this type of design option serves to increase performance by providing conditions for learning to occur; it is also a prime means for motivating students to perform since incentives which motivate man's activities come in part from the consequences of his own actions as they are understood. The issues of concern in this design approach are the following:

- Information feedback--this considers the means for providing the feedback of performance information via display design to the trainee. Included also are provisions for extra-mission equipment in the trainee station.

- Guidance supports--this concerns the provision for cues and prompts in training equipment to facilitate performance.

- Display enhancement--this refers to techniques for stimulus coding, concerned with enhancing identifiable coding dimensions by which information can be displayed optimally to the trainee in order to increase training efficiency. These techniques provide for enhancement to insure effective signal monitoring, detection and identification. A discussion of these issues has already been provided in paragraph 3.4.3 of this report.

- Mediation--this concerns decisions on the use of non-equipment options in design as a surrogate for actual equipments, vis-a-vis the purpose of training and the training objectives for a given training system.

3.7.1 Information Feedback. A desired design goal is to provide the capability in equipment for the student to know (as pertinent) how the results of his performance conform to expectations or norms. Much evidence has been assembled over many years and in many job contexts that indicates the salutary effects of knowledge of results or information feedback on learning and on performance.

Considerable research effort has been expended on differentiating the basic meanings of the term, and on delineating its empirical and theoretical properties, and a number of experiments have examined the frequency and temporal conditions relative to providing information feedback in various task situations (see, for example, the authoritative review by Bilodeau, 1966; and reports by Annett and Paterson, 1966; Micheli, 1966; Adams, 1964; Annett, 1961; Smode, 1958; and Ammons, 1956). Bilodeau and Bilodeau (1961), in their review of motor skills learning, concluded that information feedback is the strongest and most important variable in controlling performance and learning.

The evidence on the efficacy of information feedback on performance when it is provided in relevant and meaningful ways is quite clear (other than occasional contentiousness over quite detailed relationships belabored in some laboratory studies) and a review of the findings need not be undertaken here. In essence, the highlights of information feedback pertinent to design are the following:

- Learning becomes more efficient (increases in the rate and in the level of performance) as the precision of relevant information increases. Several sources of information have been identified in the regulation of performance: intrinsic feedback which is the information that the trainee receives from his own internal movements; action feedback which consists of externally displayed cues inherent in a task; and augmented feedback which refers to the availability of special information not found in the task which may be provided by an instructor or by additional feedback circuits in training equipment.

- Information feedback serves three functions: a directive effect on performance (i.e., student action to correct error), a motivating effect and a reinforcing effect on performance.

- Information feedback possesses the empirical properties of strengthening and sustaining performance, and eliminating previously established but no longer appropriate responses.

- The student may perform more nearly to his capacity when provided with information on how he is doing and how his performance conforms to expectations.

- Augmented feedback tends to become increasingly useful in either coherent or incoherent tasks, particularly during advanced stages of learning because of the more precise information given to the learner.

- It is indicated that augmented feedback increases the rate of improvement early in task practice and that it raises the level of performance in overlearned tasks. It also accounts for the frequent reports to the effect that tasks are more interesting and less fatiguing when achievement information is provided than when this information is withheld. Generally, the more precise the information and the more immediate the presentation, the greater the facilitating effect on performance. The important feature is the recognition that the ultimate performance criterion is often too gross for the trainee to appreciate increments of improvement. What is required is moment-to-moment availability of relevant information on how the results of performance conform to some objective reference.

Since training device design is at issue here, our interest centers on the display of augmented feedback to the trainee. This is a special case of information presentation in which the student is provided a signal immediately after responding which indicates the adequacy, correctness, or accuracy of his performance. This information is not available in the learning task per se, but is provided via control from the instructional system.

With the obvious advantages for training afforded by the information feedback loop, the human factors issues concern the possible means for implementation and display in training equipment. A number of design options are available for providing supplementary or augmented information feedback to the trainee.

3.7.1.1 Error Information Provided in Primary Displays. Evidence indicates that skill learning is more efficient with dynamic information feedback (immediately as accrued) then when this supplementary or extra information is withheld or when knowledge of performance is provided after task completion. With the automatic computer scoring capability, error information, as accrued, can be displayed on a primary trainee display. This technique is applicable to all training devices in which the student(s) utilizes electronic displays in job performance. A typical example of this use if found in the Simulator for Electronic Warfare Training (SEWT), described earlier in this report, wherein it is proposed that errors committed by the trainee in emitter signal analysis be shown, in alpha-numeric form, on the CRT display he uses for emitter signal analysis (specifically in this case, the AN/ALR-27). The information feedback is terse, providing essential elements indicating equipment locus and error type, e.g., "ALA-6 WRONG POLARITY."

3.7.1.2 Displays of Information. Another form of information augmentation involves the use of variations in the number of displays which provide information for control skills. Laboratory research has found differences in the performance of simple tasks as a function of number of displays employed. Tracking studies (Briggs, 1961; Briggs, 1962) which varied the scheduling of displayed information during the acquisition of vehicle control skills in the sequence of training, found that in the early stage of learning, the trainee responded almost exclusively to system error amplitudes whereas with high skill attainment he utilized error amplitude and error rate information and also determined his controlling responses by reference to the acceleration characteristics of system error. Briggs implies that the trainee requires more displayed information on the derivatives of system error early in training than he does at a later stage, based on the following reasoning: "A display in instantaneous system error amplitude contains information on error rate and acceleration which the operator himself may estimate by observing the display indications over time (the rates and accelerations of cursor movement). Thus, it is possible to maintain a reasonably accurate heading in an aircraft by reference only to the gyro compass, since the pilot can observe not only the extent (amplitude) of heading error at any time, but also, he can note the rate at which the compass is rotating and the extent to which his flight path is accelerating away from the desired heading. However, it is obvious that only the highly skilled pilot can operate effectively under such partial-panel conditions, and in order to hold a particular course without undue oscillations around the desired heading, the less skilled operator requires the bank and turn indicator plus the artificial horizon (displayed derivative information)." Briggs (1962, pg. 1). A follow-on study examined the hypothesis that a training schedule which progressively reduces the number of displays used in vehicle control (two dimensional tracking task) will enhance training compared with training that begins with a reduced number of displays. However, the display of visual information on error rate, error acceleration and information on error during training did not enhance transfer to displays showing error only. The lack of significance in the results was in part attributed to the 2-display task being too easy.

3.7.1.3 Automated Information Feedback Display. The most recent research emphasis concerning the computer control of information feedback to the student is based on an automated feedback/guidance capability and an automated monitor, evaluation and scoring system. A study by Faconti, Mortimer and Simpson (1970), exemplifies this effort. They examined, in a flight simulation context, the feasibility of various automated approaches to providing information feedback and guidance to the student via system hardware. The automated feedback and guidance capability is predicated on an automated monitoring, evaluation and scoring system in the training device which provides the signals for defining and selecting the message requirements as a function of student error in relation to preset tolerances. Also, the automated measurement system provides a priority signal (when required) which determines which message to output in the event more than one is pending. Within the audio, visual and proprioceptive modalities, the available information feedback and guidance approaches are excerpted in the following. A summary of these feedback and guidance approaches is also provided in Table 34.

Audio

- Composed Messages (Words/Syllables). The sequence of words/syllables to compose the required message is stored digitally in computer core, disk, or drum. All possible messages are stored in memory, and the proficiency measurement programs will identify the required message, specifying the message number, code, or address. The system will decode the number and thereby determine the word sequence and output the correct sequence.

- Composed Messages (Phonetics). This approach stores phonetic sounds and composes each word and each message by sequencing the correct sounds. Each message stored contains the sequence of sounds and the spacing to construct messages.

- Nonverbal Messages. This approach uses an audio frequency as the information feedback. The evaluation program, based on trainee response, selects an audio frequency band corresponding to the parameter out-of-tolerance. The deviation of the trainee's response from the desired response is proportional to the change in audio frequency from the center frequency of the selected frequency band. For example, in the flight simulator, when the pitch angle exceeds tolerances, the performance evaluation program determines that pitch angle is in error and selects the frequency band corresponding to pitch angle being in error.

TABLE 34. SUMMARY OF FEEDBACK AND GUIDANCE APPROACHES

PARAMETER APPROACH	MODALITY	*	LIMITATIONS	METHOD OF MESSAGE GENERATION	REQUIRED STUDENT INTERPRETATION	STORAGE MEDIUM	COMPUTER STORAGE	EXPANSION CAPABILITY	MESSAGE UNIT STORAGE	HI/MED/LO	COMPLEXITY SYSTEM* 1-5
Composed I	Aural	B,Q	time	Compose Units	Low	Magnetic Photo Graphic	Moderate	Limited by Hdwe	Words	Hi	2
Composed II	Aural	B,Q	time	Compose Units	Low	Magnetic	High	Limited by Comp.Memory	Sounds	Hi	4
Non-verbal Mess	Aural	B,Q	Degrees of Freedom	Analog	High	Computer	Low	Very Limited	Sound Frequency Amplitude Duration	Lo	1
Insetting	Aural	N	time	Cont Voice Tape Composed	Low	Tape, Photo, Magnetic	Moderate	Virtually Unlimited	Phases, Words	Hi	3
Continuous Messages	Aural	B	time, Hdwe	Cont. Audio Voice Tape	Low	Audio Tape	Low	Limited by Hdwe	Complete Mes.	Med	2
Model	Visual	Q	Model Degrees of Freedom	Position of Display	Moderate	Computer	Moderate	Limited by Model Movements	N/A (Dynamic)	Med	3
Inst Drive	Visual	N	Available Inst	Position of Needle on Inst	Moderate	Computer	Low	Limited by No. of Inst.	N/A (Dynamic)	Med	4
2 Pointers	Visual	N	Available Inst	Position 2nd Needle	Moderate	Computer	Low	Limited by No. of Inst.	N/A (Dynamic)	Med	3
Inst Indicator	Visual	Q	Available Inst	Light Motion	High	Computer	Small	Limited by No. of Inst.	Light Sequencing	Med	3
HUD Symbolic	Visual	Q	None	Symbol Movement	Moderate	Computer	Moderate	Limited by Display Capac.	Symbol	Hi	5
HUD Verbal	Visual	N	Visual time Acuity	Composed Words	Low	Computer	High	Limited by Core	Characters	Hi	5
Cutaneous	Proprioceptive	Q	Degrees of Freedom	Analog Vibrations	High	Computer	Moderate	Limited by DOF	Vibrations Freq. Duration	Low	4
Kinesthetic	Proprioceptive	N	Timing	Move Controls	Low	Computer	High	None (Max. to begin)	N/A (Dynamic)	Med	4

* Information Content
B -Binary
Q -Qualitative
N -Quantitative

* 1 Lowest

(from Faconti, Mortimer and Simpson, 1970.)

- Audio Insetting. This approach assumes a small number of standard formats for the total message requirement. The standard formats are stored on some continuous type of audio medium (tape, cartridge, etc.). The key words describing the parameter of interest and the direction of deviation are inserted in the appropriate position.

- Continuous Messages. In this approach, each feedback message is stored as an addressable item, and for each feedback message desired, a storage slot is required.

Visual

- Model. For flight simulation, this approach presents an aircraft model to the trainee and feedback is achieved by moving the model along the axis which is found to be out-of-tolerance in a manner that indicates the corrective action required. A closed circuit television (CCTV) technique is used to present the model to the trainee, with the image presented on a heads-up display to reduce the attention requirements on the trainee. The use of a physical model, however, provides some distortion. For example, if the model's longitudinal axis is aligned with the aircraft longitudinal axis, small changes in pitch will be undetectable. Therefore, if a change in pitch is required, the model is rotated about the yaw axis to present a side view to the trainee.

- Instrument Drivers. This approach requires activation of the instrument associated with the parameter requiring correction, for altitude the altimeter, for pitch or roll the HDI, etc. One technique to accomplish this is to develop a function to drive the indicator during feedback cycles. This is accomplished by driving the instrument from the actual value to the desired value on a cyclic basis.

- Two-pointer Instruments. Visual feedback may be given by modifying the instruments. Each pointer-type instrument could have redundant pointers with contrasting colors. The size is also relevant: the feedback pointer must be smaller in both length and width such that when not in use it is not apparent on the instrument face and can be hidden behind the normal pointer.

- Instrument Indicator Lights. This approach utilizes miniature indicator lights built in the face of selected instruments. The lights are located in a circular pattern. When information feedback is required, the lights are energized sequentially, thus giving the sensation of a moving light. The motion is in the direction of the required corrective action. An adequate number of lights is predicted to be five.

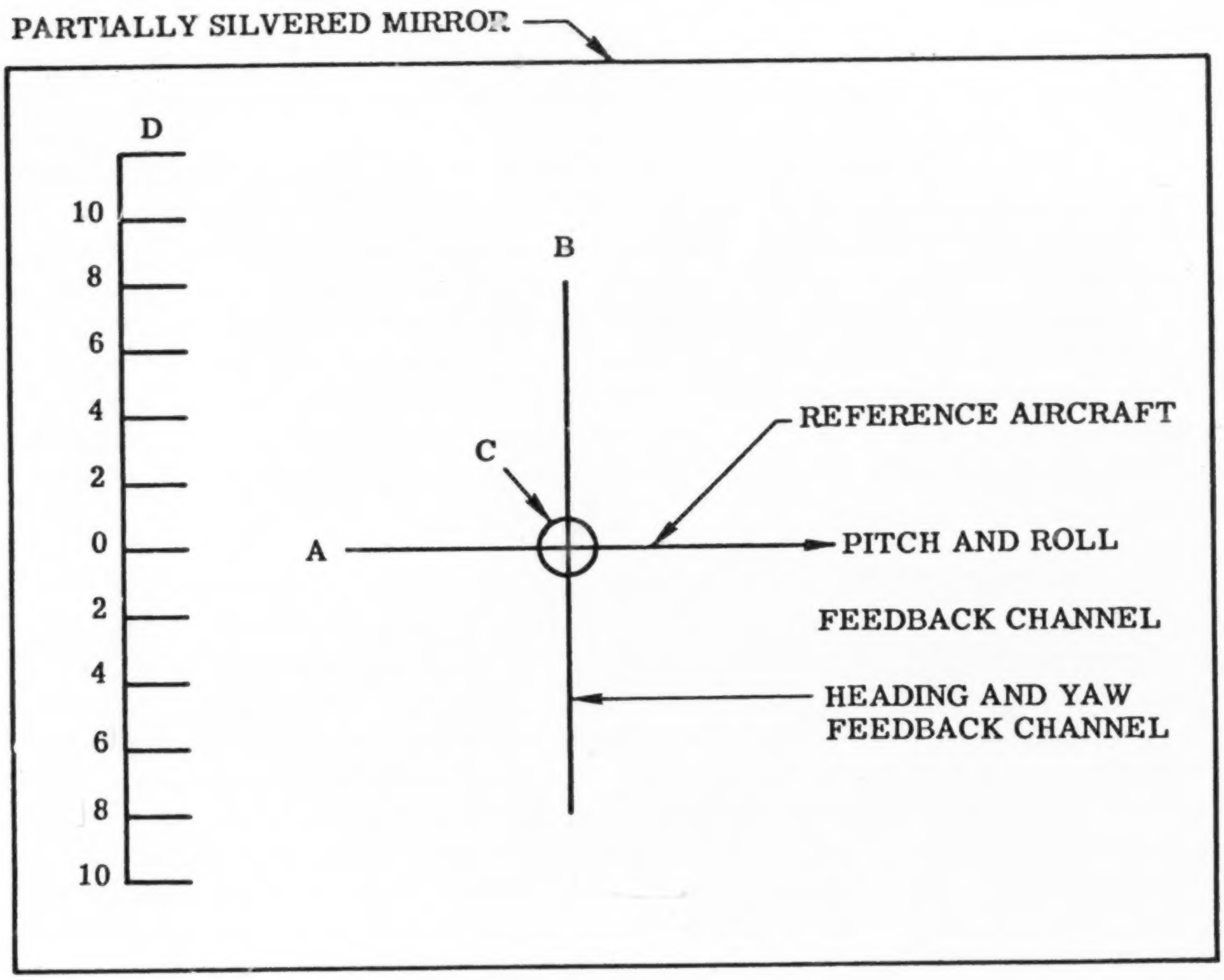
- Head Up Display (HUD) - Symbolic. Feedback may be provided through a HUD type device. One approach is to provide the feedback in the form of schematic representations of the parameters. These symbols would be similar to those presently used in the aircraft instruments and in conventional HUD. Figure 46 provides an example of this approach.

- Head Up Display (HUD) - Verbal. This approach uses the HUD to generate English Language feedback messages. Basically, the operation is the same as for audio feedback. The messages appear on a combining glass placed in the trainee's normal out-of-the-window field-of-view.

Proprioceptive

- Cutaneous Feedback. This approach utilizes the vibrotactile sense. It can be implemented by placing vibrators in contact with the trainee's skin. Varying the duration and amplitude of the vibrations provides an information channel to the man. The position on the body can be used to indicate the parameter, and the variations, in amplitude and duration, make up the message content.

3.7.1.4 Supplementary Signals. Other design possibilities are available for augmenting the feedback loop during training. These include the provision for various signals to indicate: that performance error has exceeded criterion limits; that the trend of performance is approaching an out-of-tolerance condition; or that a procedural error has occurred. To this end, auditory signals (alerting sounds, prerecorded words, computer-generated sounds based on voice synthesis), visual signals peripheral to the trainee's attention (lights), or visual signals overlaid on primary displays (discrete, patterned) are easily implemented. This type of supplementary information is of particular value during initial stages of learning by delimiting the frequency and severity of error and limiting the exploration time in performance. One purpose of this signalling is to alert the usually task-overloaded trainee to certain critical errors and error buildups that may have a cumulative effect on performance, if not modified in a timely way. This type of


PARTIALLY SILVERED MIRROR
D
10
8
6
4
2
0
2
4
6
8
10
B
C
A
REFERENCE AIRCRAFT
PITCH AND ROLL
FEEDBACK CHANNEL
HEADING AND YAW
FEEDBACK CHANNEL

LEGEND:

A - VERTICAL MOTION DESCRIBES PITCH DEVIATION RESPECT TO REFERENCE. A/C (c)

ROTATION DESCRIBES - ROLL DEVIATION

B - LATERAL MOTION DESCRIBES HEADING DEVIATION RESPECT TO REFERENCE. A/C (C)

ROTATION DESCRIBES YAW DEVIATION

C - REFERENCE A/C

D - IAS-% SCALE POSITION OF C INDICATES PERCENTAGE DEVIATION OF IAS

Figure 46. HUD Symbolic Feedback

(from Faconti, Mortimer and Simpson, 1970) performance information usually should not continue to the point where the trainee becomes dependent on extra information in job performance.

3.7.1.5 Extra-Mission Equipment. Another means for optimizing training opportunity via design is the provision for extra-mission equipments in the trainee compartment. These refer to hardware and associated training functions which are not present in operator stations in the actual system. Their purpose is to increase training flexibility and to enhance learning through the use of supplemental information (for demonstration and for information feedback) not available on the job. This feature, one of a growing number that emphasizes the "training tool" characteristics of simulators, is becoming increasingly prevalent in the design specifications for new training devices.

A representative example of this facet of instructional control is afforded by Device 2B24 (helicopter instrument flight trainer, described eariler in this report). A capability for demonstrating training problem solutions is provided in the trainee cockpit. Upon the request of the trainee or at the discretion of the instructor, demonstrations can be executed such that cockpit instruments and the motion module exhibit movements as actually flown. This may be in real time or slow time or combinations of both. A pre-recorded verbal explanation and commentary synchronized with the flight is provided. The demonstration emphasizes both didactic quality and technical accuracy to insure trainee understanding. The following problem solutions or maneuvers are envisaged to be programed.

- The interpretation of altitude and flight control instruments, including the relationships between displayed information and control movements.
- VOR approach, including reporting procedures and execution of a missed approach.
- A tactical ADF approach, including reporting procedures, wind drift correction, and execution of a missed approach.
- A standard ADF approach, including reporting procedures, wind drift correction, and execution of a missed approach.
- An ILS approach, including wind drift correction, reporting procedures, and execution of a missed approach.
- Control of the aircraft during climbs, descents, turns, climbing and descending turns and level flight by reference to attitude instruments.
- Interpretation of navigation instruments.

- Holding at an intersection, including entry from 90° off-axis, wind drift correction and departure at a predetermined time.

- An in-flight engine failure and air restart; an instrument takeoff.

The "trainer peculiar" equipments in the cockpit include: an information display panel for relevant information (status and feedback information provided the trainee); an automatic program control panel for initiating certain events (e.g., demonstration); a CRT monitor (monitored by the trainee for graphic data and for debriefing); and CCTV camera (for instructor viewing of engine and attitude instruments and trainee manipulation of aircraft controls). Voice alerts are provided (via the intercom) on parameters of flight which are outside acceptable tolerances for a given maneuver or flight condition. In addition, pre-mission briefing is automated and provided to each trainee while seated in the cockpit (Hundt, 1969).

The proposed simulator for electronic warfare training (SEWT, described earlier in this report) possesses a demonstration linkage between instructor and student to facilitate the development of an optimum training strategy per trainee. Preprogramed emitter signatures as well as specific characteristics of the preprogramed emitters can be demonstrated in the trainee compartment either during briefing/pre-mission setup or when trainee performance is below expectations during any segment of a specific mission in the training sequence.

Another form of extra-mission equipment in the trainer compartment is the annunciator panel proposed for the Multiple Trainee Station Air Navigation Trainer, Device 1D23 (Bark, et al, 1969). This offers a means of precise stimulus control for training and also provides immediate supplemental information to the trainee about the results of his performance. A number of programed questions are displayed to the student requesting certain information and specific types of behavior (e.g., calculate bingo fuel and time, calculate ETA to the next fly-to point). Each question is programed to be visually displayed at specified times in the mission cycle and remains "on" for 30 seconds during which latency of response is recorded up to 2 minutes. Failure of the student to respond (via keyboard entry) to the question in this time frame results in negative knowledge of results. In all cases, information feedback is given to the student, via the computer, immediately upon completion of response to each annunciator panel question.

A performance measurement technique that also provides the student supplemental information about performance not available in the job context is the trainee monitoring system (TMS) designed for installation in the cockpit of operational flight trainers.[1] Procedures-following sequences (computer monitored checklist events) involving both normal and emergency procedures in the mission cycle are displayed alpha-numerically on a CRT. The trainee is provided information on the adequacy of his procedural performance as accrued (i.e., in-tolerance performance and errors of omission and commission in procedural checklist activities displayed on the TMS CRT). This information is also recorded for performance measurement purposes.

3.7.2 *Guidance Supports.* Providing the trainee knowledge about performance immediately as accrued is a desirable design option in a number of training situations. Another means of providing supplementary information which has similar utility for design involves the use of cues or prompts, which provides the trainee information about performance *before* or *during* his responding. Techniques of cueing or prompting, whereby guidance is provided via the training equipment, have not been employed with any effect in training devices. However, the value of this approach for learning has been demonstrated clearly and the importance of this means of support is well recognized. Our interest concerns both the design of supports to be provided to the trainee and the assistance provided to the instructor (alerts, trend information) which will simplify and improve his instructional functions.

Considerable research on learning has indicated that task relevant guidance given to the trainee (i.e., stimulus support) is particularly useful during initial learning for it emphasizes the relevant aspects of performance, limits the exploration time and minimizes gross errors in performance. As learning progresses, these cues/prompts are eventually withdrawn until the trainee responds to the stimuli found in terminal performance (see Skinner, 1960).

Providing cues and prompts via equipment is apparently more useful in part task trainers than in complex weapon system trainers (such as multi-man tactical training devices which place a premium on engineering fidelity and one-to-one transfer of training from the device to the operational situation). In a study of sonar-like detection training (short bursts of tone presented at irregular intervals on a background of white noise), Annett (cited in Annett and Paterson, 1966) found that presenting a visual warning cue prior to each signal tone resulted in positive transfer to an uncued standard task. This cueing was found to be more effective than either immediate or summary knowledge of results. Annett and Clarkson

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[1] MIL T-82335, Military Specification, Trainers, Flight: General Specification for. Also specified as a requirement in the design for Device 2F100, Operational Flight Trainer (A-7E Aircraft), Specification 311-1112, U.S. Naval Training Device Center, Orlando, Florida, 13 November 1970.

(1964) suggest that cueing is a feasible technique for training in perceptual and monitoring tasks (e.g., sonar and radar watchkeeping) since training can be arranged to give the student maximum exposure to the relevant stimulus aspects of the task. The experimental task required the detection of a weak near-threshold auditory signal (1000 cps lasting 50 ms). A visual display consisting of four colored lights provided cue, correct response, incorrect response and missed signal information (i.e., cue and knowledge of results information). The superiority of cueing over knowledge of results was demonstrated. Both techniques showed an increase in detections but also encouraged different patterns of response by the trainee. With cueing, a decrease in percent error (false positive judgments as a percent of total response) was obtained, whereas with knowledge of results, an increase in percent error was obtained (i.e., more errors of commission). With the caution that the task was a simple monitoring situation (lacking the variety and intensity of the signal environment in actual watchkeeping situations, and with shorter vigil periods), the authors concluded that cueing provided effective exposure to authenticated signal samples for the subject to reliably learn to distinguish between signals and non-signals. Maintaining performance by learning the statistical distribution of signals during a watch period was facilitated by maximum exposure to signals (i.e., few or none of the signals were missed). It seems probable that what was learned about the signal distribution is as important as what was learned about the signal itself.

Various studies concerned with signal detectability have indicated that the use of prompts, cues, signal specification, etc., improve auditory detection performance (see, for example, studies by Gundy, 1961; Swets, 1962; and Lukaszewski and Elliot, 1962). The results indicate some value in identifying and authenticating the signal prior to its onset, however, the studies involved a number of independent variables and the effects of the signal specification on performance were not uniformly clear.

For our purposes, the function of cueing and of knowledge of performance is to provide information. Both techniques are desirable for training design. The question is, what guidelines exist for design? The work of Annett and his associates found systematic differences between cueing and knowledge of results for both detection and discrimination tasks which they interpreted to result from changes in the response criterion. In detection tasks, knowledge of results increases detection by increasing the response rate and hence the false positive rate, whereas cueing increases detection without increasing response rate or the false positive rate. The value of cueing is shown by a lowered threshold of the auditory signal, hence the trainee gets maximum experience with the signal, and is able to build up a knowledge of the signal characteristics more effectively than by means of knowledge of results. Cueing also provides a good indication of signal distribution parameters.

In essence, the feature for design is that providing subsidiary information useful to, or about performance, enhances learning. Cues/prompts ("prior to") and information feedback ("during or immediately after" performance) are useful techniques. It may be that a mixing of cueing and information feedback is optimal for training (i.e., cueing followed by augmented information feedback). However, Annett and Paterson (1967) found that cueing, knowledge of results and a combination of the two resulted in essentially equal but improved performance over a control group for pitch and intensity discrimination in a sonar-like watchkeeping task. There is not enough evidence to specify in detail when to employ cueing and prompts and in what forms, in training device design. Nevertheless, the reasonableness of the cueing feature is not easily discounted particularly when the instructor is afforded control over its usage (for example, employed during initial training and faded out as appropriate as skill is achieved).

A number of techniques have been employed in training that can be assembled under the rubric of guidance support. The use of the demonstration mode in training (described previously in paragraph 3.7.1.5) is clearly a technique of instructional guidance. Another design technique involves the use of information displays which present future or predicted information based on trainee control performance of the moment. The predictor instrument which provides a display of the response characteristic of the system in terms of predicted system output at some time in the immediate future is a representative example. The control task can be simplified by providing the operator information relative to the future of the variable being controlled. This support is of particular value during initial learning (see Kelley, 1960).

Related to this is a type of information display which provides an indication to the trainee of the immediate or successive actions required to maintain an in-tolerance condition. This approach can be implemented in various ways, for example, by means of miniature indicator lights imbedded in an instrument display which provide guidance information via a sequencing of the lights in the direction of the correction required. The rate of sequencing is proportional to the magnitude of the error. A specific application of this is a proposal by Faconti, Mortimer and Simpson (1970) (cited earlier) for a circular pattern of miniature lights built into the face of an aircraft instrument. The lights can be energized sequentially to give the sensation of a moving light in the direction of a required corrective action. The lights are not visible when performance is in-tolerance.

Guidance may also be built directly into the controls operated by the student. Controls can be mechanized to describe a desired action, for example, a pilot trainee "following through" on an automated control stick sequence which demonstrates an ideal maneuver. Limits of movement can also be built into a control to insure that a trainee does not exceed certain error boundaries (for example, the extent of control excursions is contained in order to delimit the making of gross errors in control).

3.7.3 Mediation. A valid design alternative concerns the selection of non-equipment options as part of the device configuration for achieving the purpose and the objectives of training. It should be made clear that an equally valid design decision is to not provide hardware but to use the instructor to perform certain training functions. We are using the term "mediation" to denote this design approach which reduces or simplifies the device hardware and, in lieu of hardware, employs the instructor as an integral part of the training loop.

Two aspects are subsumed under this concept: reduction (exclusion) of hardware solutions (use of the instructor) and equipment simplification (e.g., a switch or potentiometer control in lieu of a ship's helm, paper and pencil representation for an equipment component, etc.). The skillful use of these surrogates for actual equipments and the attenuations in fidelity of representation can:

- reduce significantly the cost of the training device without compromising the training effectiveness,
- pinpoint the essential training required; for example, in a team training context, design emphasis is focused on key positions while supportive positions are provided with only what is needed to interface with the primary positions,
- improve training potential by structuring the training situation and sharpening the focus on the purpose and objectives of training.

3.7.3.1 Trainee Station Options. A decision for trainee compartment design concerns the advantages in attenuating the fidelity of task representation, both in situations where a trainee position may be secondary or supportive in a team context, or where certain tasks performed by a trainee are secondary in the pattern of training objectives. A prominent case can be found in multi-man team training devices where the design alternatives are based on a selective training emphasis (focusing training on key positions in a team while other positions are only supportive) vs. an equal training emphasis (all positions are of similar training importance). A good example of this departure from realism in design is found in Device 14A2 (ASW tactical team trainer, described in Section IV of this report). The purpose of this training requires a selective emphasis in instruction, which focuses on the duty stations in three key ASW compartments (CIC, UB/plot, and sonar) since the ASW operations are critical here and the personnel interactions are of high density. The training requirements in the other compartments (Launcher Captain Control station and the Bridge) are less demanding and hence are only supportive in that these trainees serve as necessary links in the development of coordinated team sequences. Thus, there is no requirement for high fidelity in ship steering dynamics. The design decision resulted in a simple potentiometer control for steering the ship, instead of the controls normally found on a ship's bridge.

Another example of mediation in design is found in Device 14A6, ASW Coordinated Tactics Trainer. Sonar contact reports are provided through paper and pencil messages in lieu of detections made from actual sonar displays. Theoretically, this is a valid design option since the simulator is a tactical decision-making trainer involving large numbers of naval units and various force compositions. The sensor stations are relegated to a supportive role in the overall training purpose and objectives and sufficient operational validity is provided to achieve the training objectives without synthesizing the entire sonar facility. This, however, requires well developed and precisely executed utilization procedures (series of training exercises) for the device.

3.7.3.2 Instructor Involvement. The use of mediation, involving the instructor in lieu of training hardware, depends largely on the trainee-instructor relationship requirements and on tradeoffs in equipment instrumentation. The decision on whether to mediate should begin with the understanding of the trainee-instructor relationships. A useful technique for systematically examining where instructor mediation could be reasonably substituted for hardware is to array, in matrix form, the mission or job sequences against required trainee behaviors. Cell entries in such a matrix can be made to indicate those event/behavior points at which instructor involvement can be effectively traded off for hardware. For example, the variety of information feedback requirements to the trainee may be prohibitive in terms of equipment. Answers to such questions as, "How fine should the information about performance be?" and "How complex should the provided cues/prompts be as a function of level of training?" will determine the cost/benefit of mediation solutions. The more complex the behaviors (relative richness) the more (logically) the instructor should be involved in the training. This tradeoff depends on the ease with which instrumentation can be achieved. For example, if the number of categories of information to be provided the trainee during the course of instruction presents problems in storing the information, then the instructor may usefully serve to provide information to the trainee (as required) in lieu of equipment presentation. A case in point is the presentation of ground-to-air communications to pilot trainees. To instrument feedback mechanisms for a reasonable universe of messages that might be required in the total set of training exercises incurs an inordinate equipment burden, whereas the use of the instructor for this purpose is at present, a more logical solution.

3.7.4 Research Issues. A systematic effort is suggested to place in perspective the transfer of training benefits that accrue from the selection of training device design options that are deliberate departures from operational realism. The positive values for learning and performance resulting from supplementary and augmented information and from signal enhancement techniques are well documented. The basic question concerns their various utilities for simulator training and how they can be most efficiently implemented. A number of the techniques currently employed have been selected more on a logical than experimental grounds or based on results obtained in task contexts quite dissimilar to those involved in complex synthetic training situations. A number of issues worthy of consideration are outlined below.

a. A base of experimental data should be accumulated on the effects of supplementary information feedback and guidance supports on performance in simulator training. This should center on the kinds of job situations and training equipments that would benefit from this approach; quantitative data on transfer of training effects should be collected.

b. The indications are that guidance supports are of greater training value in part-task devices than in weapon system trainers. The effects of guidance supports in generalized/universal training devices should be examined vis-a-vis transfer of training to the operational counterparts.

c. Greater definition of cues, prompts, and signal specification is required as guidelines for design. This includes the varieties and forms of relevant guidance supports and patterns of usage for design. A legitimate question, for example, concerns the fineness of gradations of these supports as well as the differential utility of this fineness for training, if any.

d. A research issue of some priority concerns the role of feedback and guidance as supplementary information in automated training situations. The questions concern the available options for design, the means of implementation, the credibility of the information (realistic, timely, sufficient) that is automatically presented, and the training values afforded by this approach.

e. A straightforward requirement is to put into perspective the range of information feedback, guidance support, and signal enhancement techniques available within the state-of-the-art, the means for their implementation and the relative cost considerations.

SECTION IV

DEMONSTRATION OF HUMAN FACTORS RECOMMENDATIONS IN THE DESIGN OF A COMPLEX SHORE-BASED TEAM TRAINER

4. INTRODUCTION

The purpose of this section is to provide a well developed example of human factors involvement in the training system design process. A demonstration is provided of the human factors inputs to the design of device 14A2, ASROC/ASW Early Attack Weapon System Trainer. What is presented is a reconstruction of the human factors design process for achieving the functional specifications for the device. The points where human factors inputs influence the design of the system are systematically explored, using the method described in Section II of this report. Within this framework of a human factors design method overlaid on an operational synthetic training system, the congeries of design issues are organized and the options available to design are examined. The net effect is an examination of the human factors design of a complex training system already in existence.

The luxury of viewing an on-line training system in retrospect provides an opportunity to examine the credibility of the method proposed in this report, particularly in relation to the design achieved. It also provides the opportunity to reconstruct the key design decision points and to explore the design alternatives to determine what effects, if any, these modifications would have had on the configuration of the device and on training capability.

The reconstruction which follows is based for the most part on independent analyses made by Dunlap and Associates, Inc., organized within the method described in Section II. Where use is made of Navy reports or other published data, this information is documented.

The presentation is deliberately terse, in which the reader is taken through the steps in the design process. Only the key design decision points, those that significantly influence the configuration and hence the utilization of the device, are emphasized, since the definition of, and the rationale for, the sequence is discussed in Section II. The identification and resolution of design issues will not receive the full blown treatment as would be expected in the human factors report for any system under study.

Thus, the highlights of the results which are most meaningful to human factors design are stressed. While the highlights are outlined in a sequential, or step series, it is worth repeating that the process is iterative in that the data gathering and organization proceeds from gross to detailed levels of analysis.

4.1 DEFINITION OF PURPOSE OF TRAINING. The purpose of training is defined by an NTDC team and personnel from the cognizant operational using agency. The NTDC team, which prepares the Military Characteristics (MC) for the device, is usually made up of the Project Officer (Requirements), an Engineer and a Human Factors Specialist.

The decision has been made that an ASW Team Trainer is needed and Fleet requirements specify a shore-based ASROC/ASW Early Attack Weapon System Trainer capable of indoctrinating and training ASW surface ship crews in ASW tactics. From this start point, a number of decisions are made which define clearly the type of training system needed and which outline a design pathway to follow to most expeditiously achieve a device design consonant with the purpose of the training.

4.1.1 Characteristics of the Environment for Training and the Trainee Involvement.

4.1.1.1 Type of Training Device. A team training device is required to provide training of individuals in the team context (subteam and overall team coordination) for destroyer (DLG, DDG, Fram I) and Cruiser ASW operations.

Training emphasis is on procedural and tactical decision-making sequences that involve the coordinated efforts of the team in operating and employing the vehicle. Excluded is the basic training of individuals in their particular job requirements so that the most efficient use of the 14A2 for training takes into account that individual team members are already proficient in their billets. The concept of team training is defined in this way: individuals perform in a structured job situation wherein each member has a defined function to perform interdependent with those of the other team members; the effects arising from this interdependence of behaviors influences system performance.

Training will cover two types of situations: 1) where the ASW events are repetitive and predictable and there are specific and detailed rules and procedures for handling them; 2) where the mission events are unpredictable and where all action relevant to the environmental conditions and the state of the system have not been specified so that operations do not necessarily conform to standard procedures. Both of these situations operate in a complementary fashion in mission training.

What is stressed is the development of coordinative skills based on adequate individual skills. Two features of team performance are emphasized. The first is that team coordination develops and improves when individually skillful trainees work in an organized system environment. The second is that teams may be equivalent in overall performance, yet differ considerably in how they go about their business. Similarly, in complex tactical situations, several equally good solutions to problems often exist so that differences between teams may become evident only in the way a team copes with the ASW situation. Device design must provide a flexibility for installing these kinds of team situations.

Design Options

a. Team training would emphasize the procedures in target detection and tracking with fire control solutions and launch for ASROC and AWTT Weapon Systems, and some DASH and Vectored attacks with aircraft included. Training sequences would be conducted in one-on-one (own-ship and submarine) tactical environments and progressing to rudimentary screening mission contexts and then to search and attack unit (SAU) missions.

b. Team training would emphasize tactical employment of the vehicle over a substantial range of ASW missions involving threat evaluation and multi-unit coordinated search and attack operations as prescribed in Doctrinal Publications. This embraces tactical situations where the events are unpredictable and where all action relevant to the engagement geometry have not been specified.

Decision

Device design will provide coordinated training in team procedures and in tactical decision making such as found in operating and tactically employing an ASW vehicle in representative "hot war" situations. Team coordination will be exercised to include complex multi-unit operations in SAU contexts involving a range of search and attack plan operations as presented in Allied Naval Maneuvering Instructions, ATP-1 (A).[1]

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[1] Allied Naval Maneuvering Instructions (U), ATP-1 (A) (Change 6) Vol. I (C).

Note: The Navy specifications for the Device[1] call for:

- Basic team training covering the operation of the individual subsystems, the communication and coordination requirements in tactical situations.
- Advanced team training covering tactical procedures in both normal and casualty modes and tactical problems under stressful operational conditions.

4.1.1.2 Selection of ASW Training Areas for the Device. The trainer shall represent the ASW configuration and operational compartments and equipments as defined for surface ships and their ASW attack weapons. The compartment functions include target search and detection, target tracking, threat evaluation and action selection and implementation as represented by fire control solution and weapon launch. The team training to be achieved requires the following shipboard areas to be simulated for training.

Underwater Battery Plot (UB/Plot)--This is the ASW attack center and contains the attack consoles of the fire control equipment and associated communications equipment.

Sonar--This contains the equipment for sonar target acquisition and tracking and associated communications equipment.

Combat Information Center (CIC)--This is the center for the collection, evaluation, display and dissemination of the overall tactical situation. Plots are maintained on friendly and hostile units, maneuvers and tactics recommended and control of the DASH vehicle and Vectored attacks are the responsibilities of this compartment.

Launcher Captain's Control Station (LCCS)--This compartment ensures proper system attack progression. From here, the directions are given for positioning the launcher, selecting a cell and selecting a missile or torpedo (ASROC, AWTT). Also, auxiliary firing is accomplished here and missile firing safety features are controlled.

Conning Station (Bridge)--This compartment recommends and approves orders for coordinated action of own-ship and conducts the maneuvering of own-ship.

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[1] Specification for Trainer, Weapon System, ASROC/ASW Early Attack Device 14A2 (U), U.S. Naval Training Device Center, 3231-220, March 1964. (Conf.)

4.1.1.3 Definition of System Components

Design Option: To provide specific system suites vs. generalized training equipment for ASW operations.

Decision: A direct transfer of training is desired from Device 14A2 to the ASW platform of the destroyer or cruiser since the teams eligible for 14A2 training will be drawn from operational units when these units are in port. The training device will be utilized in direct support of operational destroyer/cruiser ASW personnel. Ideally, team practice in the device should be highly realistic to actual operations aboard ship and the system suites in the device should be equivalent to those found aboard ship and in similar configurations. Therefore, the compartment spaces, equipments and operating modes in the 14A2 should be similar to, or replicas of the equipment suites aboard destroyers (DLG, DDG, FRAM I) and Cruisers.

- SQS-23 Sonar, Mk 114 Fire Control system
- SQS-23 Sonar, Mk 111 Fire Control system (as required) (with provisions for the SQS-26 to be employed in the future)
- Relevant equipments in the ASW compartments.

4.1.1.4 Levels of Training. Emphasis is placed on the maintenance of proficiency of destroyer/cruiser ASW personnel in team operations (procedures) and on advanced team training in multi-unit exercises such as found in screening operations and in SAU contexts involving a representative range of search and attack operations.

4.1.1.5 Training Emphasis

Design Option: Provide design for an equality of training emphasis among all trainees in the team vs. design for a selective emphasis which focuses training on key positions in the team context.

Decision: Training focus and fidelity of representation is centered on the duty stations in three key ASW compartments since the critical ASW operations are performed here and because of the high density of interactions among personnel in these compartments. These are: CIC, UB/Plot, and Sonar. The training requirements and synthetic training equipment needs in the LCCS and the Bridge (Conn) compartments are less demanding, either in terms of the frequency of involvement or of training purpose, for example, no requirement for high fidelity in ship steering dynamics. These trainees serve most effectively as necessary links in the development of coordinated team sequences in the device.

The core of the trainee population will be individual ship personnel who will be assigned and trained as a team in the device. For the key Sonar, UB/Plot and CIC positions, personnel will already be qualified in their billets. Other individuals may or may not be qualified.

It is anticipated that the training of individual ship's teams will be conducted on a recurring basis, in that a ship will be scheduled for the trainer, when in port, on a cyclic basis and as appropriate to fleet scheduling. A team, for example, may be assigned for two days of training on a quarterly basis. Thus, the training exercises and the development of utilization practices for the device must account for this scheduling in the sequence of training.

4.1.1.6 Implications for Fidelity of Simulation. There are considerable requirements for procedural and for control sequences involved in the fundamentals of ASW operations in subteam and team performances. They center on the development of coordinated procedures and internal communications in achieving fire control solutions and launch of the weapons systems available. These requirements are also involved in operating own-ship when exposed to basic submarine tactics, torpedo hydrophone effects, equipment casualty, and maneuvering for attack and lost contact procedures in a one submarine-one ship situation. In screening and SAU contexts similar requirements exist under more difficult conditions and in addition, include Vectac operations, procedures in coordinated search and attack plans, and inter-unit communication procedures. Thus, device configuration must provide a training environment conducive to the realistic accomplishment of the following:

- Procedures in search and detection
- Maintenance of contact and tracking
- Procedures for readying weapons systems for attack
- Appropriate utilization of communication circuits
- Procedures in the prosecution of targets.

These operations require a high fidelity in the representation of the controls and displays of individual equipment components in the subteam spaces. Replicas of much of the operational equipments are required. These are described in Section 4.4, Gross Device Definition.

Higher order tactics training involving tactical doctrine and team decision-making sequences in threat evaluation and weapon assignment is, in large part, mediated in the organization of training. The development of device utilization procedures will account for structuring and controlling the series of training exercises to accomplish the training objectives set forth. As such, few additional demands are placed on hardware to accomplish this level of training. There is, however, an exception to this that requires a major design decision. The design option deals with the issue of extent of simulation (e.g., what/how much to simulate) and is concerned with the representation of those simulation elements that provide the sonar classification capability. (This is discussed in Section 4.5.1.2.2.)

4.1.1.7 Device Dynamics. Computer programing is required to provide the following:

Own-Ship Characteristics

- Simulated motions realistically displayed on sonar, radar, NC-2 plotter
- Instrument readouts to correspond to ship maneuvers-realistic control lags with ordered speed and course changes.

Other Vehicle Characteristics

- Realistic sensor displays of motion for target vehicles, surface ships, aircraft and DASH

  (speeds, turn radius, rate of change in depth/altitude, acceleration/deceleration).

Weapon Characteristics

- Current weapons and their characteristics
- Current weapon delivery systems and their characteristics

  (ASROC, AWTT. DASH, Aircraft)

- Realistic weapon deployment procedures
- Post-launch dynamics--realistic display representation (ASROC trajectory, weapon water running times, torpedo hydrophone effects).

Platform Motion Simulation (Yaw, pitch, roll)

- No requirement for platform motion for team training in ASW procedures and tactics.

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Real-World Visual Simulation

- No requirement for outside-the-platform visual representation. Visual requirements center on the electronic displays (Sonar, Fire Control, Radar).

4.1.2 Provisions for the Management of Training at the Instructor Station

4.1.2.1 Instructional Staff. Design should account for three or more instructors in training exercises: a chief instructor at the master console and two remote instructors located in the UB plot-sonar and CIC. Additional instructors may be employed at the master console or as needed in the trainer compartments depending on the stage of training and level of exercise difficulty.

4.1.2.2 Training Device Mode of Operation

Design Option: manual vs. preprogramed exercise sequencing.

Decision: selection of a manual mode for enroute exercise control. The use of automated training sequences (preprogramed scenarios) and selected adaptive training exercises were considered and rejected in order to achieve greater flexibility in instructional control to account for significant differences among teams in entry-level skills and for differences in time available for training among teams.

4.1.2.3 Pre-Mission Requirements. Provision should be made for a team briefing/critique space. Mission briefing will be conducted prior to the actual conduct of each training exercise. Briefings for training exercises of a similar type (repetitive) may be accomplished remotely in the spaces with trainees emplaced. Communications capability for this will be provided (see Section 4.5.1.1).

4.1.2.4 Approach to Monitor and Control of Training During an Exercise. Manual control of each exercise will be provided throughout the exercise (via a training utilization guide which provides training exercise scenarios graduated in difficulty). The instructor is provided control, display and communications capabilities to establish the initial conditions for each exercise, to control own ship, target and media variables during the course of the exercise and to monitor trainee performance. A projection display system (showing a history of the exercise) is envisaged to provide instructional assists.

4.1.2.5 Performance Monitoring/Assessment

Design Option: manual vs. automatic scoring system.

Decision: selection of a manual technique involving scoring based on instructor judgments for assessing individuals within the team and team performance. The situational display of the total mission via the projection display will provide indicants of system performance (e.g., geometry of the engagement as it unfolds, and weapon firing in terms of water entry point).

Design Option: record keeping of individual team performances vs. only the on-site critique of team performance after each exercise.

Decision: Verbal on-site critique using the projection display of the engagement; no quality control provisions involving additional device hardware or computer software programing. Hard copy records of performance (for critique purposes and school record keeping purposes) will not be provided.

4.1.2.6 Post-Mission Requirements. Critique of performance will be conducted after completion of each exercise for the assembled team in the briefing/critique space. Projection display equipment will be employed for mission reconstruction of each exercise.

4.1.2.7 Configuration of the Instructor Station. The problem control room will house the instructor station and will provide space for team briefing and critique functions. The projection display system will also be located here.

The consoles which make up the instructor station will be organized on the basis of a modular design concept with indicators and controls grouped by related functions on each console. The following integral modules are required: vehicle control (own-ship, support ships and aircraft, target submarine); fire control (fire control system, launcher system and weapons); sonar; radar; and support (environmental controls, communications, projection display controls).

4.1.3 Output

The articulation of the purpose of device 14A2 provides the initial concept of the training system. This scoping or "roughing out" of the system between NTDC personnel and the using agency training personnel provides the focus for the subsequent iterations leading to the decisions on the functional characteristics that define the training device. The design issues identified in this initial analysis are further defined and explicated in the subsequent analyses.

4.2 ORGANIZING INFORMATION ON THE OPERATIONAL SYSTEM.

The definition of training purpose provides the essential outlines for the 14A2 training system. This has established a basis for what must be represented in the device, the magnitude of, and the types of training required and gross concepts about the fidelity of simulation in the device hardware. It also provides the basis for the analysis of task structure and the definition of the characteristics of the operational environment to be represented in the training system.

An analysis of ASW operations is now begun to gain the necessary familiarization with those portions of the operational system on which the training device is based.

4.2.1 System Description. Highlights of the system descriptive information pertinent to device design are outlined below. Greater detail within categories is not shown, but is suggested by the organization of the information.

4.2.1.1 ASW Missions

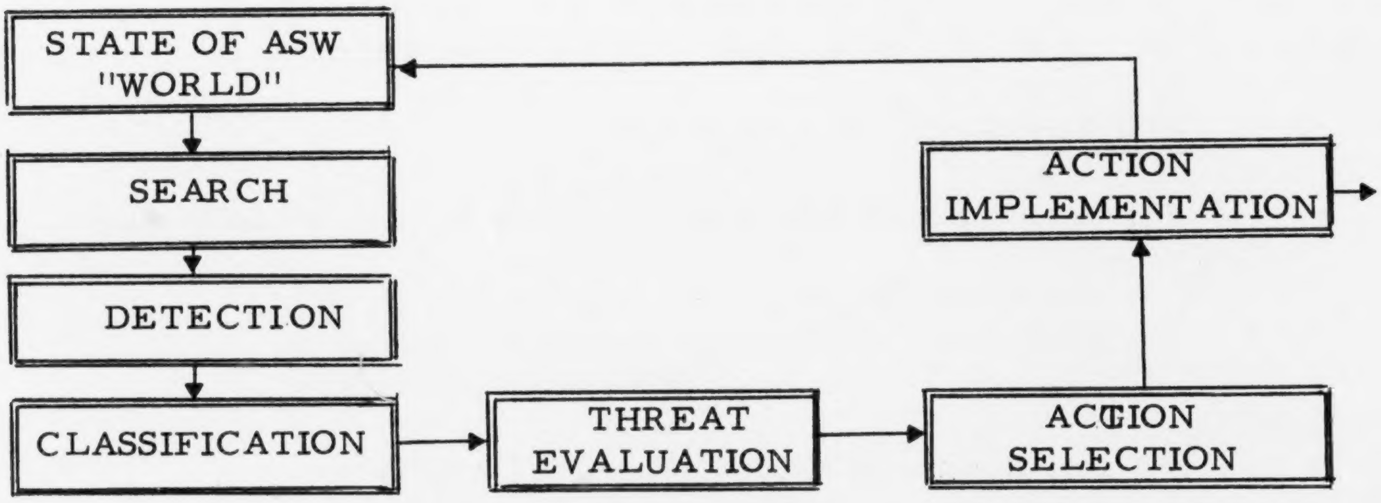
The range of ASW destroyer missions involve the following:

- prevention of submarine mission in an area (SAU context--detection and classification of submarine, killing or deterring submarine)
- intelligence gathering, warning (large area surveillance, focal area surveillance)
- protection of commercial shipping (sanitization of an area or lane, screening of a convoy)
- escort of naval forces (screening of naval forces, sanitization of harbor exits and entrances)
- countering of submarine in local area (screening and deterring submarine, blockade)

With minor exceptions, these missions are applicable to general or limited war with or without conventional weapons for the following combinations of destroyer forces:

- destroyer or destroyer escort
- DD and HS
- DD and VP
- DD and VS
- DD and SS
- DD and SS and VP/VS/HS

To maximize the training effectiveness of device 14A2, two broad mission contexts, in a "hot" war situation are defined as the environment for training. These are the screening context and the search and attack unit (SAU) context. The following is the basic ASW paradigm:


STATE OF ASW "WORLD"
SEARCH
DETECTION
CLASSIFICATION
THREAT EVALUATION
ACTION SELECTION
ACTION IMPLEMENTATION

Screen. Screen elements protect more vulnerable units being screened by employing diversionary or agressive measures. Exercises in the screen area will deal with sustained ASW operations in or near the main body of an operating force as distinguished from SAU exercises where the destroyers may start out in a screen, but become a SAU as soon as they are detached for prosecution in an area remote to the main force. Screen exercises will deal somewhat with position-keeping and control of search aircraft on the screen, but more heavily with the prosecution of submarines inside or very near the screen. Two examples of the foregoing are:

- Urgent attack from Condition III Watch on a contact detected inside the screen or the TDZ of the destroyer
- Coordinated search for a submarine suspected of being inside the screen or very near the formation (ex.: the use of such plans as Pumpkin 51S, Beetroot 52S, and Carrot 53S)

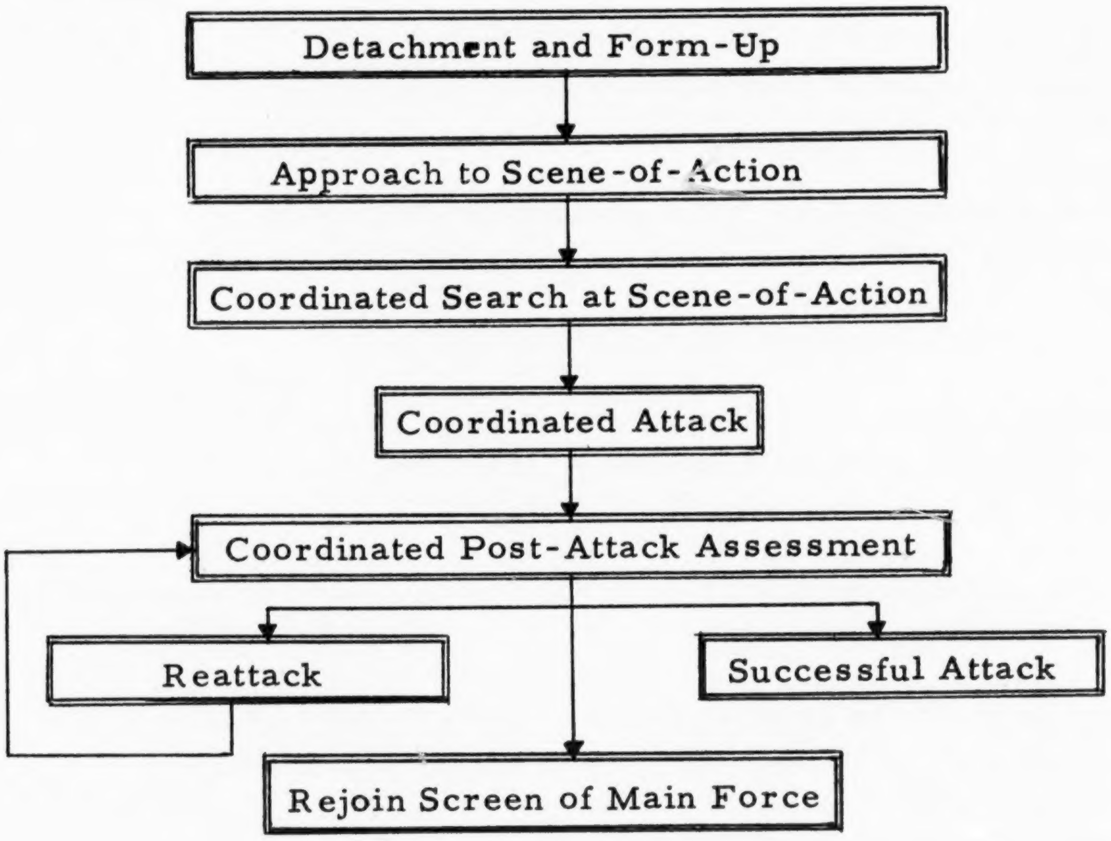
Training in such activities as the initial configuration of screening units, the selection of units to compose a SAU, reconfiguration of a screen following the departure of elements assigned to a SAU, is considered a function of the screen commander or the OTC. As such, these are higher level tactical decisions now thought to be inappropriate for training on the 14A2. More appropriately, such tactical decision-making training might better be accommodated on a training device where the portrayal of the dynamic geometry of multiple units is more comprehensive, and with extensive and more sophisticated communication possible among greater numbers of participating unit and force commanders. (Device 14A6, ASW Coordinated Tactics Trainer, provides this kind of training.)

Search and Attack Units (SAU). SAU operations involve the prosecution of a datum or contact by coordinated surface/air forces, whose primary purpose is to search and "successfully engage" enemy submarines. The training emphasis in Action Selection and Implementation will be on SAU operations, since considerable doctrine exists for SAU missions and which can be trained in the 14A2. The compositions of SAU's presently considered for training are grouped into three basic classes: one destroyer plus aircraft; two destroyers; and two destroyers plus aircraft. These groupings supply realistic operating requirements to be implemented in Device 14A2. The destroyer complement of SAU's has been limited to a maximum of two ships based on the operating forces suggestion that more than two ships in a SAU may frequently impair overall coordinated performance, especially in the attack phase.

The destroyer complement of a SAU can originate from a variety of screen formations (circular, bentline, etc.), which in turn are part of larger operating forces. The operating forces presently considered as a source of supply for the destroyers of a SAU are:

- Hunter Killer (HUK) Force (Destroyer and A/C SAU's)
- Strike Force (Destroyer-only SAU's)
- Merchant/Naval Convoy (Destroyer-only SAU's)

SAU operations begin when an OTC or Screen Commander designates and dispatches a destroyer element (normally preceded by an air element in the case of a HUK force) to prosecute a datum or contact, and encompass the following phases of operation:


Detachment and Form-Up
Approach to Scene-of-Action
Coordinated Search at Scene-of-Action
Coordinated Attack
Coordinated Post-Attack Assessment
Reattack
Successful Attack
Rejoin Screen of Main Force

Early SAU exercises for the 14A2 device should look at destroyer performance in all phases. However, as exercises become more complex/ difficult (more units, more aggressive and evasive targets, degraded environment) such phases as detachment and form-up, early stages of approach for distant transits, and rejoining will be mediated to conserve training time and allow for focusing on the more crucial search and attack phases.

4.2.2 Functions of ASW Subteams. The major functions performed by the subteams in ASW operations are outlined next.

SONAR

- Conduct sonar search; use beam-to-beam procedures or sweeps of search arcs.
- Detect, classify, and track a target; provide current sonar target range and bearing to CIC, UB Plot and Bridge.
- Determine and report target aspect from doppler (audio).
- Detect and classify torpedo and submarine hydrophone effects.
- Conduct "no echoes" and lost contact search procedures.

UB PLOT

- Perform target motion analysis on sonar contact and develop a fire control solution (target course and speed, WEP). Provide developing FCS information to CIC and Bridge.
- Select ASROC or AWTT weapon delivery system, homing weapon (Mk 44, 46 homing torpedo) and fire ASROC or AWTT.
- Provide aided tracking (director control) to sonar when fire control solution is smooth.
- Provide vectoring information for control of DASH (back-up method to those available in CIC).
- Deploy and activate material countermeasures (Fanfare); provide required underwater communications (Gertrude).

CIC

- Recommend coordinated search plans (area and lost contact), attack and support methods, torpedo countermeasures, and torpedo evasion techniques.
- Monitor conduct of coordinated search, recommend maneuvers for own-ship and surface support units.
- Control ASW Air Control Net: Coordinate search functions of VS aircraft under advisory control; vector HS aircraft to dips (positive control) in extended search lines, dip stations, and search vectors.
- Control use of RADAR and ECM; detect, classify, and track significant surface contacts (submarine, snorkel, periscope, friendly forces); detect and classify electronic emissions.
- Maintain a plot of own-ship, own-ship contact, surface support units, support unit contacts, guide.

- Compute and/or Plot:
  - DATUM, datum time (to include a fix on two ECM bearings, radar, sonobuoy, sonar, visual SOSUS).
  - Farthest on Position Circles
  - Torpedo Danger Area (TDA)
  - ETA to TDA
  - CPA's
  - Torpedo Danger Zone (TDZ)
  - Limiting Lines of Approach
  - Danger Zone
  - Water Entry Point
  - Firing Lane and Impact Area
  - Weapon Run-outs
  - Torpedo Hydrophone Effects (bearings)
  - Knuckles
- Maintain display of important tactical information (tailored to individual ship needs) on status boards.
- Control SAU CI and ASW Common Nets; send, receive, and disseminate initial contact reports, SWAP reports, amplifying reports and SITREPS, weapon arming and firing reports.
- Report entry into TDA, recommend appropriate torpedo countermeasures.
- Determine if bearing/range of initial contact is "clear" or "foul" (via surface radar)
- Determine submarine course and speed from NC-2 plotter or DRT plot.
- Dead reckon submarine course and give EP's, recommend sonar search arcs when contact is lost.
- Vector DASH to and from drop point; control weapon drop(s).
- Control ASW Air Control Net; conduct vectored attacks using HS or VS aircraft under positive control.
- Recommend maneuvers to hold contact prior to attacks (keep contact out of baffles).

- Recommend and/or concur weapon selection and firing time.
- Recommend turn after weapon launch; control ship during post-attack assessment.

BRIDGE

- Exercise tactical control of own-ship and other support units of SAU, while performing roles of SAU Commander and SAC.
- Maneuver own-ship; control course and speed via engine orders and rudder angle control.
- Approve all search plans, attack and support methods, torpedo countermeasures, and weapon launches.
- Control PRITAC and SAUTAC Nets; transmit initial contact report (PRITAC) and maneuvering orders to other ships of SAU (SAUTAC).
- Assure ship safety.

LCCS

- Approve all weapons launches.
- Provide backup firing capability in case of malfunction.

4.2.3 Man-Machine Interactions

4.2.3.1 ASW Stations and Operator Duties

A total of twenty-two personnel are involved in the ASW operations of concern for device 14A2. These represent the essential manning requirements for the UB plot, Sonar, CIC, Bridge and LCCS subteam compartments to accomplish the range of coordinated training desired in the 14A2.

CIC Compartment

Personnel	Duties
Evaluator	Supervises the NC-2 and DRT plotting functions, evaluates contact from the plot.

Personnel	Duties
Evaluator (Cont.)	Supervises CIC external Voice communications, and disseminates evaluation and progress of attack.
	Prescribes search arcs to Sonar or recommended search plan to the Bridge as required (IJS circuit).
	Keeps Bridge informed of tactical situation and makes appropriate recommendations for the employment of own-ship and sensors.
	Recommends appropriate search plans and employment of other units when operating in multi-unit context.
	Provides Bridge with maneuvering information when designated as assisting ship.
CIC Officer	Controls the radiotelephone nets for rapid communications with other ASW units.
	Supervises the communications with aircraft.
	Recommends aircraft employment to the CO.
	Supervises the conduct of VECTACS and MADVECS and other aircraft operations in accordance with existing instructions.
	Functions as assistant evaluator.
No. 1 - Plotter	Maintains plot of contact and own-ship on NC-2/DRT plot.
	Receives sonar tracking (range and bearing) information (61JS circuit).

Personnel	Duties
No. 2 - Plotter	Maintains plot of assisting ships and aircraft and of their contacts on NC-2/DRT plot. Mans the radar information circuit (22JS), receives and plots range and bearing information on surface contacts being tracked.
Surface Radarman	Detects, classifies surface contacts. Provides tracking information (range and bearing) on surface contacts over 22JS circuit. Determines if bearing/range of initial contact, "clear" or "foul."
ECM Operator	Detects and classifies electronic emissions.
Radar Supervisor	Supervises the operation of radar. Provides assistance as required by Evaluator in areas of external communications and plotting functions (NC-2/DRT).
ASAC	Mans ASW Air Control Net and controls VS and HS aircraft as directed, to include the routine control of HS dip cycles, advisory control of VS search operations, HS and VS VECTAC's.
Status Board Operator	Plots significant ASW tactical information as required by the CO and the Evaluator.
UB/Plot Compartment	
ASW Officer	Verifies target data by monitoring sonar azimuth and range indicator for comparison with geographic plotter of attack console.

Personnel	Duties
ASW Officer (Cont.)	Reports solution of target classification course and speed to Bridge and CIC and compares with their solution.
	Responsible for control of Fanfare.
	Directs the attack operation of all manned ASROC components (via 1JS circuit).
	Coordinates missile selection with the CO.
	Directs firing of the ASROC missile when authorized by the CO.
	Controls all ASW stations from UB plot.
	Ensures that contact reports and classification are promptly and properly disseminated.
	Recommends courses of action to execute the ASW attack and the ordnance to be used.
	Mans the 1JS phone circuit.
Geographic Plotter	Operates the geographic plotter sections of attack director (A/D).
	Determines the submarine's course, speed, target angle, range rate, firing time, weapon train, and other data important to the attack and to ship safety.
	Directs and monitors attack console operations as ordered by the ASW officer.
	Controls aided tracking and position keeping tracking in conjunction with sonar.

Personnel	Duties
Geographic Plotter (Cont.)	Monitors digital computers and provides input data necessary for fire control solution.
Firing Panel Operator	Controls weapons station(s) (via JA or 8JP circuit) and informs the ASW officer of its status.
	Controls the use of safety devices at weapons stations.
	Operates the firing control panel to fire the designated weapon(s) (ASROC, AWTT)
Sonar Compartment	
Sonar Supervisor	Assists the ASW officer in supervision of sonar control.
	Provides the ASW officer with continuous contact evaluation.
	Responsible for proper sonar search procedures and evaluation of sonar information.
	Reports contact information over 1JS circuit.
Sonar Operator	Conducts sonar search as specified by CIC using standard doctrine and procedures.
	Reports all initial contacts to ASW stations via 29 MC.
	Makes preliminary contact evaluation and classification.
	Tracks all contacts.
	Reports any evidence of torpedoes or submarine countermeasures.

Personnel	Duties
Standby Sonar Operator	Assists the search operator as required.
	Relays all information from the search operator to the Bridge, CIC, and UB plot (via 61JS circuit).
	Relieves the search operator, as required, to alleviate strain of continuous concentrated effort.
Bridge Compartment	
Commanding Officer*	Responsible for all ASW procedures and tactics, approves tactical recommendations.
	Supervises the coordination with other ASW units, and ordering of coordinated search and attack plans.
	Approves weapon selection.
	Directs sonar employment.
	Makes final decision on target classification.
	Responsible for own-ship safety.
Officer of the Deck (OOD)	Verifies that all stations are properly manned.
	Visually checks contact bearing and reports, "bearing clear or foul."
	Compares target characteristics from sonar, UB/plot and CIC.
	Shifts control between Bridge, UB plot and CIC.

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*Listing the CO as part of the Bridge complement does not imply that the CO should be physically located there throughout a training exercise.

Personnel	Duties
Officer of the Deck (OOD) (Cont.)	Issues orders for own-ship maneuvers.
JOOD	Assists the OOD and CO. Monitors RT circuits. Mans the 1JS circuit during ASW action. Assumes the conn if so ordered.
Surface Radarman	Monitors positions of surface support units.
RT Talker	Maintains communications between own-ship and other support units (PRITAC, SAUTAC, Screen Common Nets).
Helmsman	Controls ship's course and speed via rudder angle and engine orders.

Launcher Captain's Control Station Compartment

Console Operator	Operates the LCCP Mark 199. Ensures proper system attack progression. Monitors operation of the relay transmitter, Mark 43. Reports detected malfunctions to ASW officer (via 8JP circuit). Verifies that all inputs have reached launcher and that launcher is operating properly. Responsible for weapon launcher in the event of failure at the Attack Director Console.

4.2.3.2 Sequence of Operations in the System. An operational sequence diagram is used as a means to graphically present the interactions of men and equipment in the system operating sequence. Table 35 presents the sequence of operations for destroyer ASW functions. The most complex mission environment is depicted (SAU operations) to show the relationships among the major operating compartments of CIC, UB/Plot, Sonar and Bridge.

4.2.4 Sources of Information

- System observation and discussions with knowledgeable operating personnel
- System Documentation (official Navy Publications) (Confidential)

- NWP-24-C	ASW Operations
- NWIP-24-1(A)	Antisubmarine Classification Manual
- ATP-1(A)	Allied Maneuvering Instructions
- ATP-28	Allied ASW Manual
- ASAC	Handbook, antisubmarine Control, COMASWFORLANT
- NAVPERS 10140	Sonar Technician 1st and Chief
- NAVPERS 10131	Sonarman 3rd and 2nd
- NAVPERS 10147-C	Radarman 1st and Chief
- NAVPERS 10144-A	Radarman 3rd and 2nd
- NAVPERS 10823-B	Combat Information Center Officer

4.3 ANALYSIS OF TASKS INVOLVING HUMAN PARTICIPATION. Effort is now devoted to identifying and organizing the activities involved in subteam and team performance in order to make decisions about characteristics of the training system. This is done to the level of detail needed to define the simulation elements that should be represented by the device to achieve the purpose of training.

4.3.1 Operational Structure. Task structure is developed from the system analysis data and from the major ASW functions performed. It centers on the key ASW positions where the highest density of interactions are involved. Satisfying the performance requirements in the CIC, Sonar and UB/Plot compartments and to a lesser extent in the LCCS and Bridge compartments, has the greatest impact on design.

For the purpose of this report, task analyses are presented below for two of the key subteams: CIC and Sonar. Similar analyses would be conducted for UB/Plot, Bridge and LCCS compartments, but are not shown here. Tables 36 and 37 are CIC analyses; Table 38 is the Sonar analysis. The analyses consider the most complex mission, that of SAU operations.

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION

Assumptions:

1.) A destroyer type (e.g. a FRAM I) with an SQS-23 Sonar, MK114 Fire Control System, and ASROC/DASH/AWTT weapon delivery systems.

2.) A hot war situation exists

LEGEND

○ —Information Received

□ —Action Performed

⬡ —Determination/Decision

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION

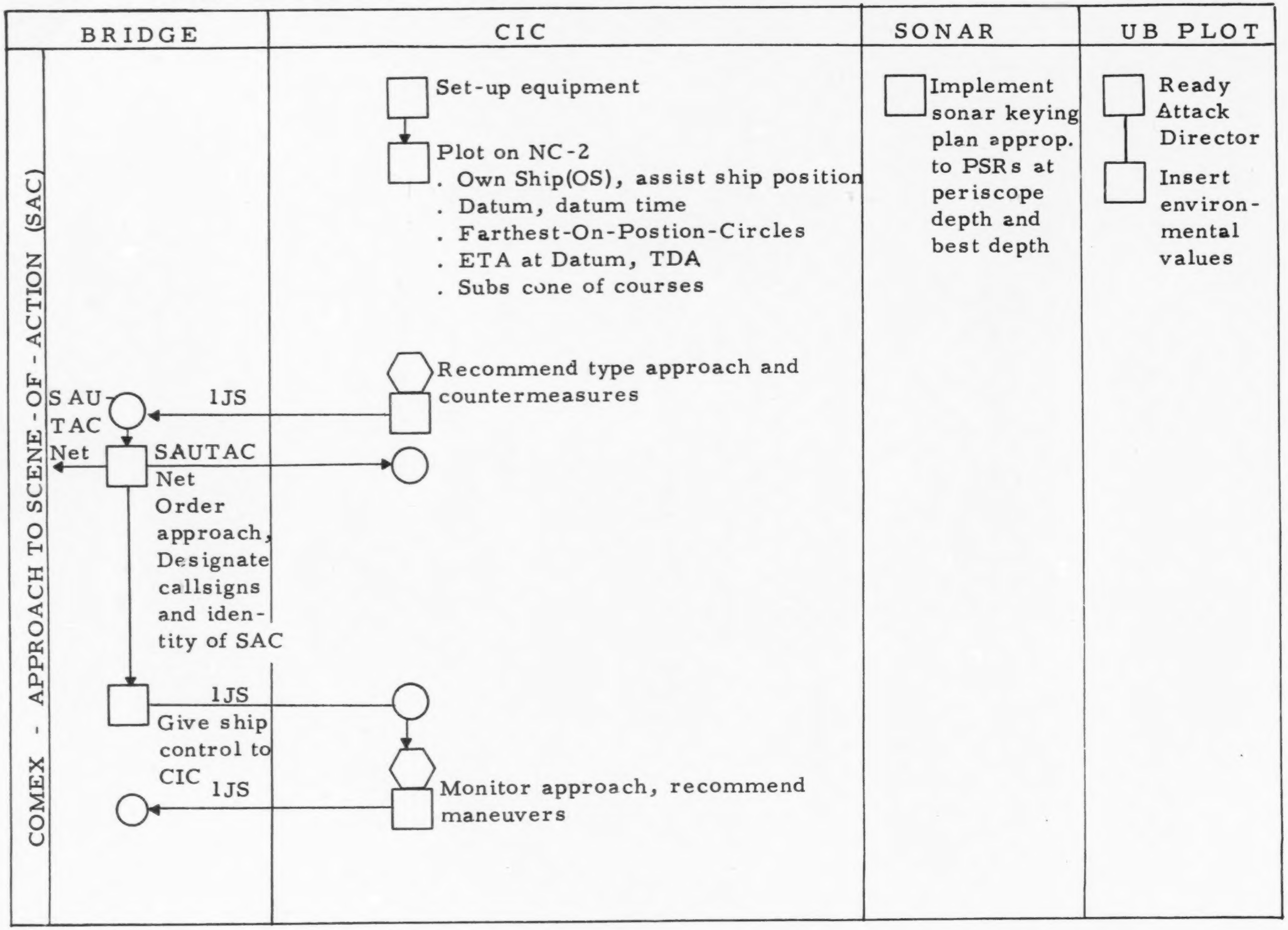
BRIDGE
CIC
SONAR
UB PLOT
COMEX - APPROACH TO SCENE - OF - ACTION (SAC)
Set-up equipment
Plot on NC-2
. Own Ship(OS), assist ship position
. Datum, datum time
. Farthest-On-Postion-Circles
. ETA at Datum, TDA
. Subs cone of courses
Implement sonar keying plan approp. to PSRs at periscope depth and best depth
Ready Attack Director
Insert environ-mental values
Recommend type approach and countermeasures
1JS
SAU-TAC Net
SAUTAC Net
Order approach, Designate callsigns and iden-tity of SAC
1JS
Give ship control to CIC
1JS
Monitor approach, recommend maneuvers

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

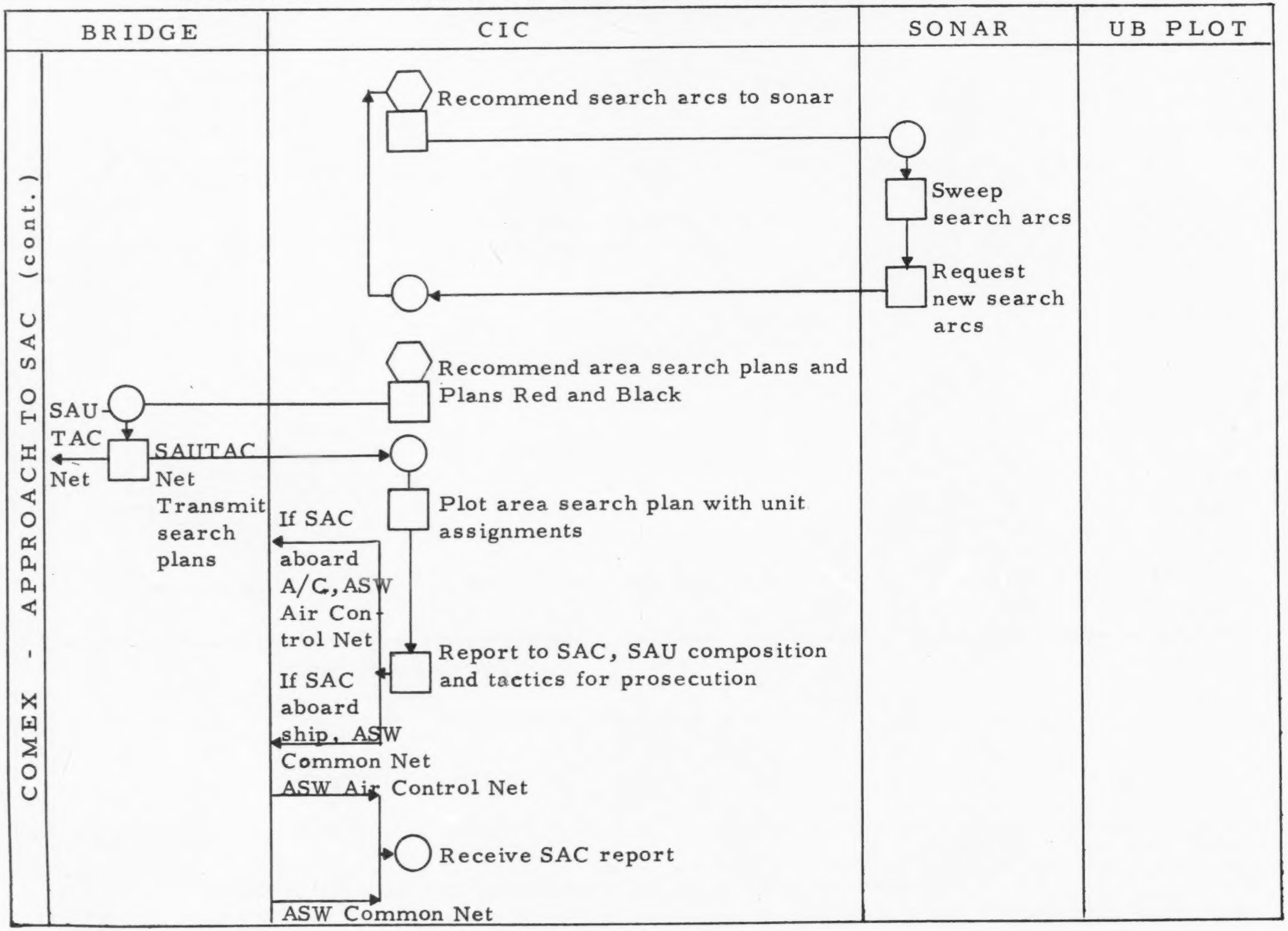
BRIDGE
CIC
SONAR
UB PLOT
COMEX - APPROACH TO SAC (cont.)
Recommend search arcs to sonar
Sweep search arcs
Request new search arcs
Recommend area search plans and Plans Red and Black
SAU-TAC Net
SAUTAC Net
Transmit search plans
Plot area search plan with unit assignments
If SAC aboard A/C, ASW Air Control Net
If SAC aboard ship, ASW Common Net
Report to SAC, SAU composition and tactics for prosecution
ASW Air Control Net
Receive SAC report
ASW Common Net

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

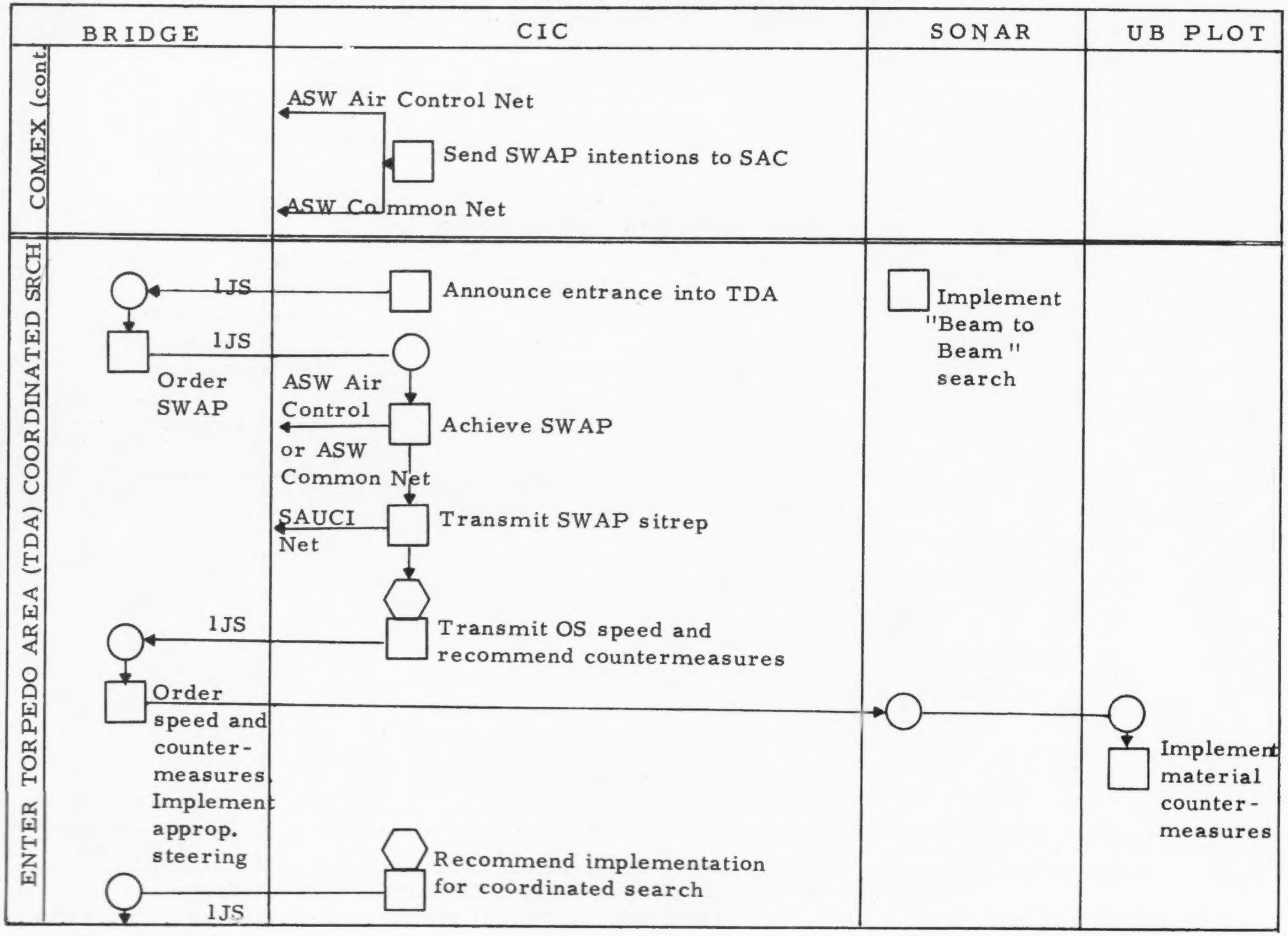
BRIDGE
CIC
SONAR
UB PLOT
COMEX (cont.
ASW Air Control Net
Send SWAP intentions to SAC
ASW Common Net
ENTER TORPEDO AREA (TDA) COORDINATED SRCH
1JS
Announce entrance into TDA
Implement "Beam to Beam" search
1JS
Order SWAP
ASW Air Control or ASW Common Net
Achieve SWAP
SAUCI Net
Transmit SWAP sitrep
1JS
Transmit OS speed and recommend countermeasures
Order speed and counter-measures. Implement approp. steering
Implement material counter-measures
Recommend implementation for coordinated search
1JS

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

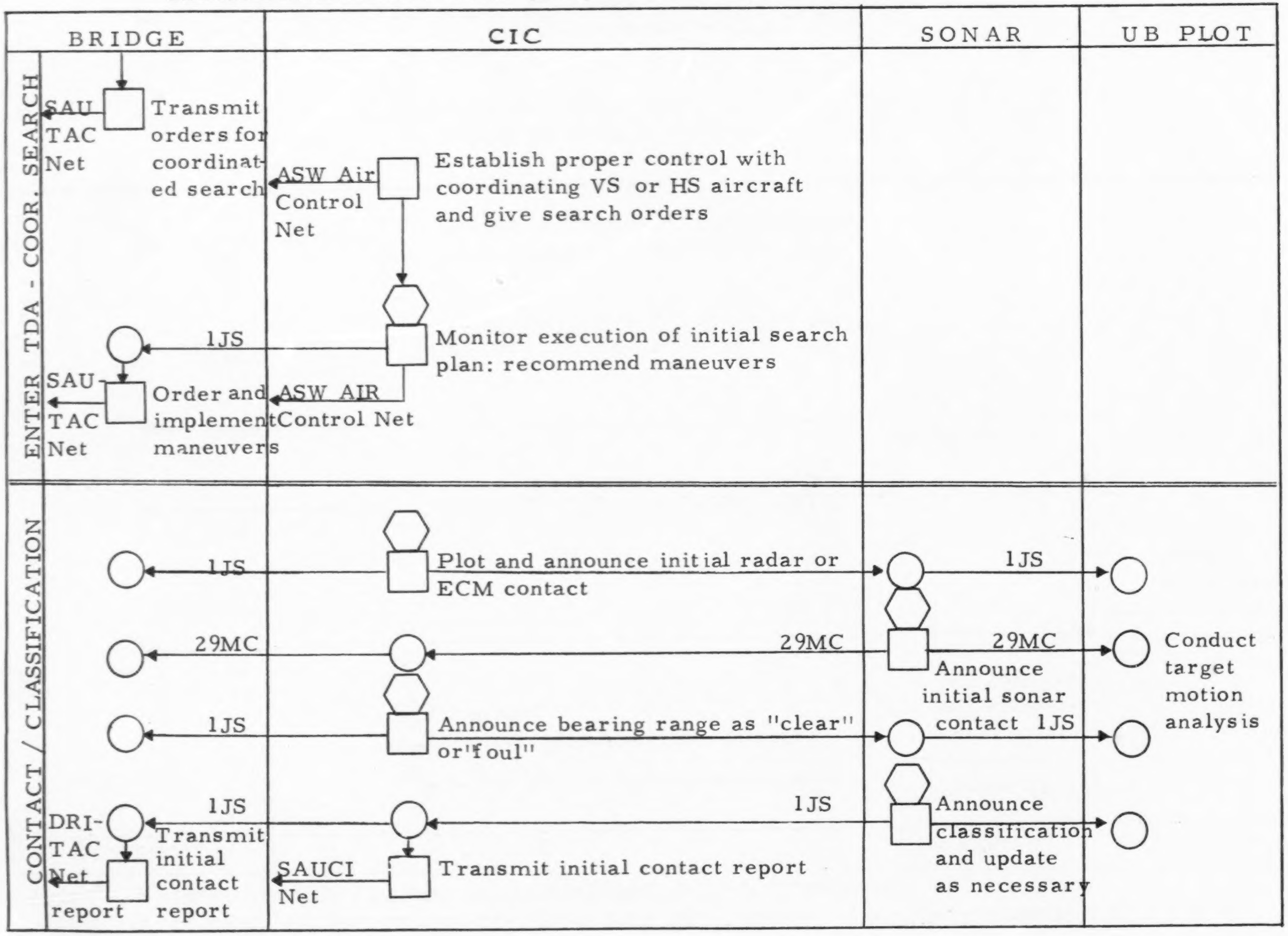
BRIDGE
CIC
SONAR
UB PLOT
ENTER TDA - COOR. SEARCH
CONTACT / CLASSIFICATION
SAU TAC Net
Transmit orders for coordinated search
ASW Air Control Net
Establish proper control with coordinating VS or HS aircraft and give search orders
1JS
Monitor execution of initial search plan: recommend maneuvers
SAU-TAC Net
Order and implement maneuvers
ASW AIR Control Net
1JS
Plot and announce initial radar or ECM contact
1JS
29MC
29MC
29MC
Announce initial sonar contact
1JS
Conduct target motion analysis
1JS
Announce bearing range as "clear" or "foul"
1JS
1JS
1JS
Announce classification and update as necessary
DRI-TAC Net report
Transmit initial contact report
SAUCI Net
Transmit initial contact report

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

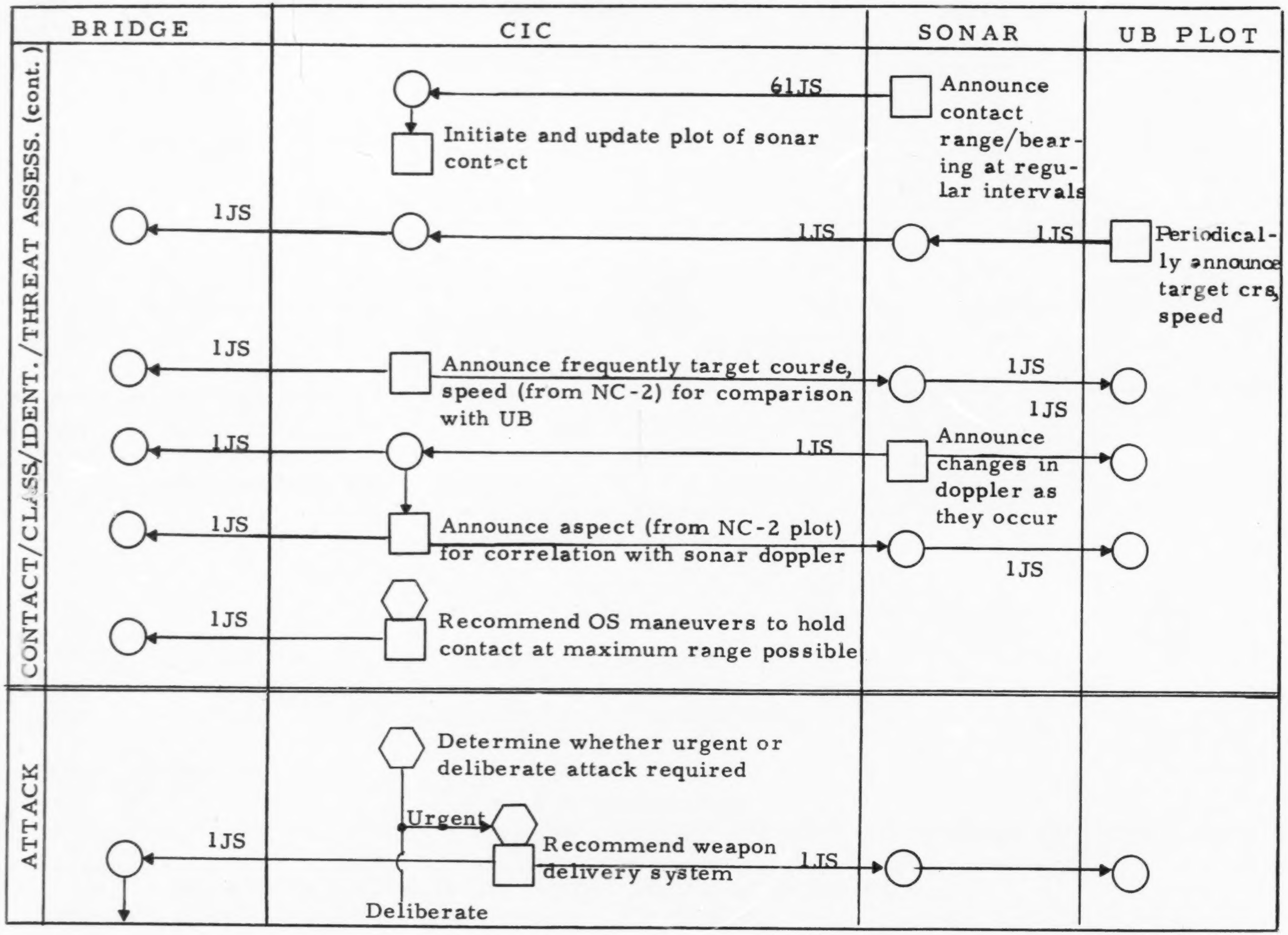
BRIDGE
CIC
SONAR
UB PLOT
CONTACT/CLASS/IDENT./THREAT ASSESS. (cont.)
61JS
Announce contact range/bearing at regular intervals
Initiate and update plot of sonar contact
1JS
1JS
1JS
Periodically announce target crs, speed
1JS
Announce frequently target course, speed (from NC-2) for comparison with UB
1JS
1JS
1JS
1JS
Announce changes in doppler as they occur
1JS
Announce aspect (from NC-2 plot) for correlation with sonar doppler
1JS
1JS
Recommend OS maneuvers to hold contact at maximum range possible
ATTACK
Determine whether urgent or deliberate attack required
Urgent
1JS
Recommend weapon delivery system
1JS
Deliberate

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

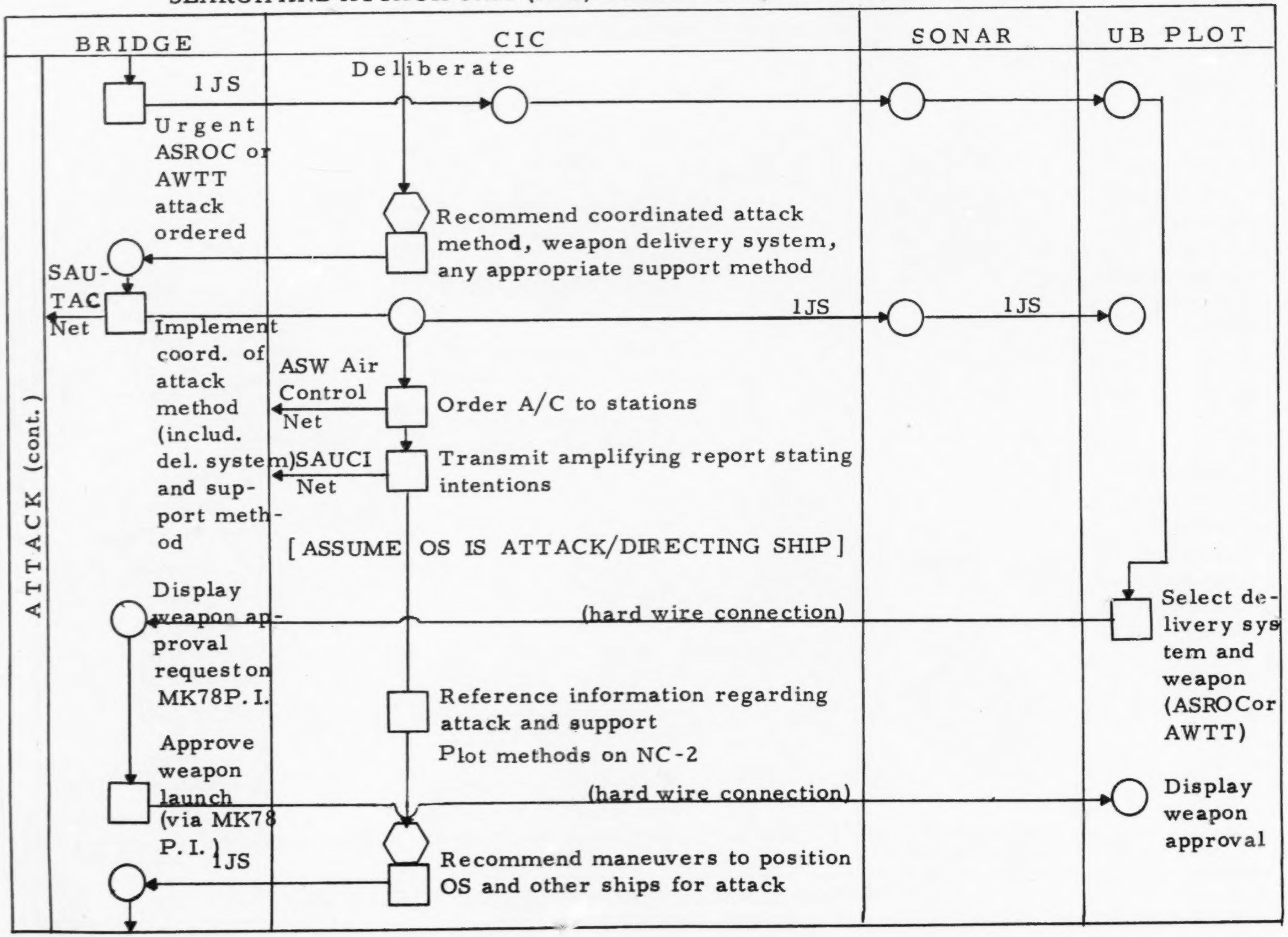
BRIDGE
CIC
SONAR
UB PLOT
ATTACK (cont.)
1JS
Deliberate
Urgent ASROC or AWTT attack ordered
Recommend coordinated attack method, weapon delivery system, any appropriate support method
SAU-TAC Net
1JS
1JS
Implement coord. of attack method (includ. del. system and support method
ASW Air Control Net
Order A/C to stations
SAUCI Net
Transmit amplifying report stating intentions
[ASSUME OS IS ATTACK/DIRECTING SHIP]
Display weapon approval request on MK78P.I.
(hard wire connection)
Select delivery system and weapon (ASROC or AWTT)
Reference information regarding attack and support
Plot methods on NC-2
Approve weapon launch (via MK78 P.I.)
(hard wire connection)
Display weapon approval
1JS
Recommend maneuvers to position OS and other ships for attack

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

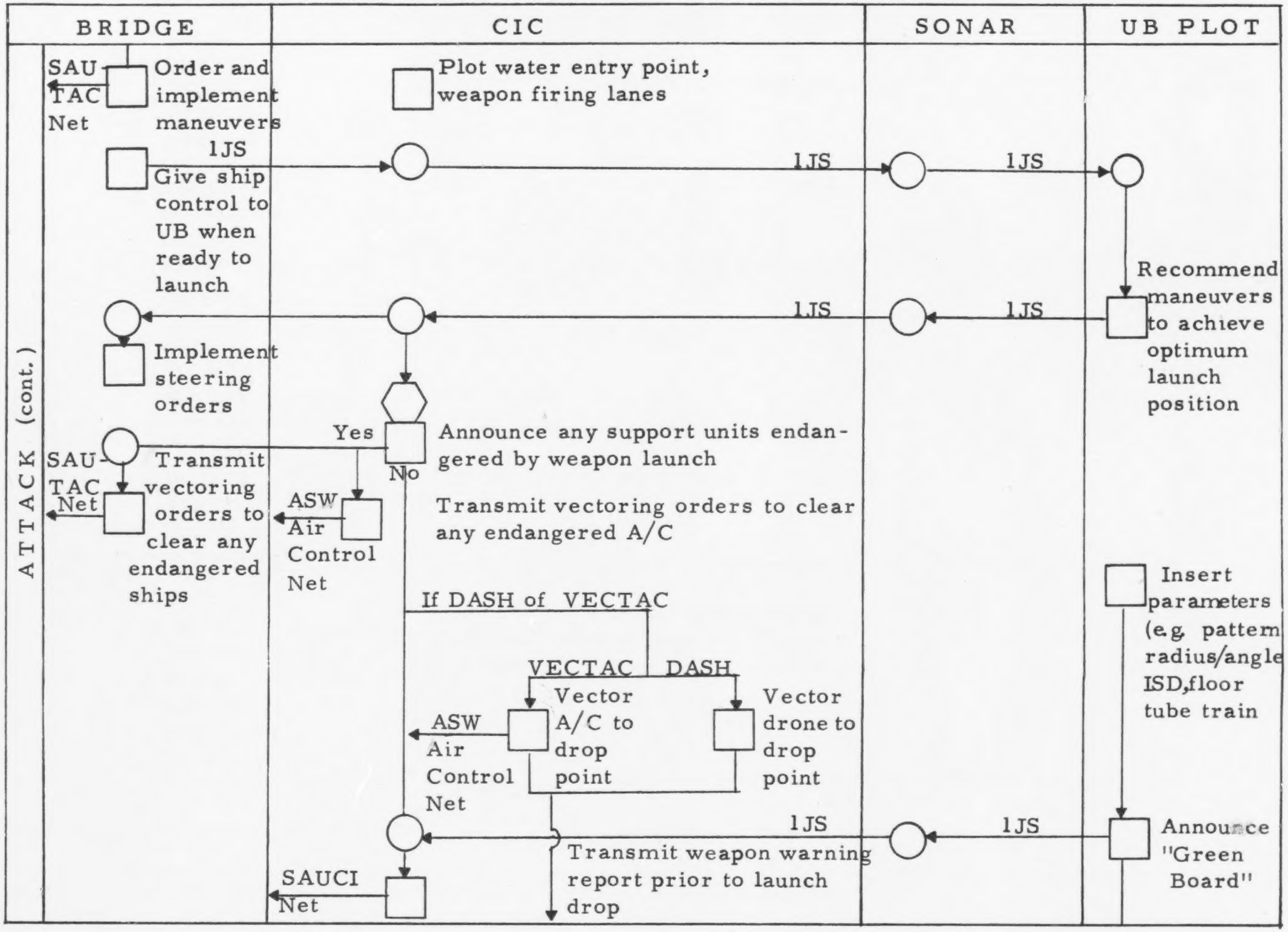
BRIDGE
CIC
SONAR
UB PLOT
ATTACK (cont.)
SAU TAC Net
Order and implement maneuvers
Plot water entry point, weapon firing lanes
1JS
Give ship control to UB when ready to launch
1JS
1JS
Recommend maneuvers to achieve optimum launch position
1JS
1JS
Implement steering orders
Yes
No
Announce any support units endangered by weapon launch
SAU TAC Net
Transmit vectoring orders to clear any endangered ships
ASW Air Control Net
Transmit vectoring orders to clear any endangered A/C
Insert parameters (e.g. pattern radius/angle ISD, floor tube train
If DASH of VECTAC
VECTAC
DASH
ASW Air Control Net
Vector A/C to drop point
Vector drone to drop point
1JS
1JS
Announce "Green Board"
SAUCI Net
Transmit weapon warning report prior to launch drop

TABLE 35. OPERATION SEQUENCE DIAGRAM FOR DESTROYER ASW FUNCTIONS INVOLVED IN A SEARCH AND ATTACK UNIT (SAU) OPERATION (Continued)

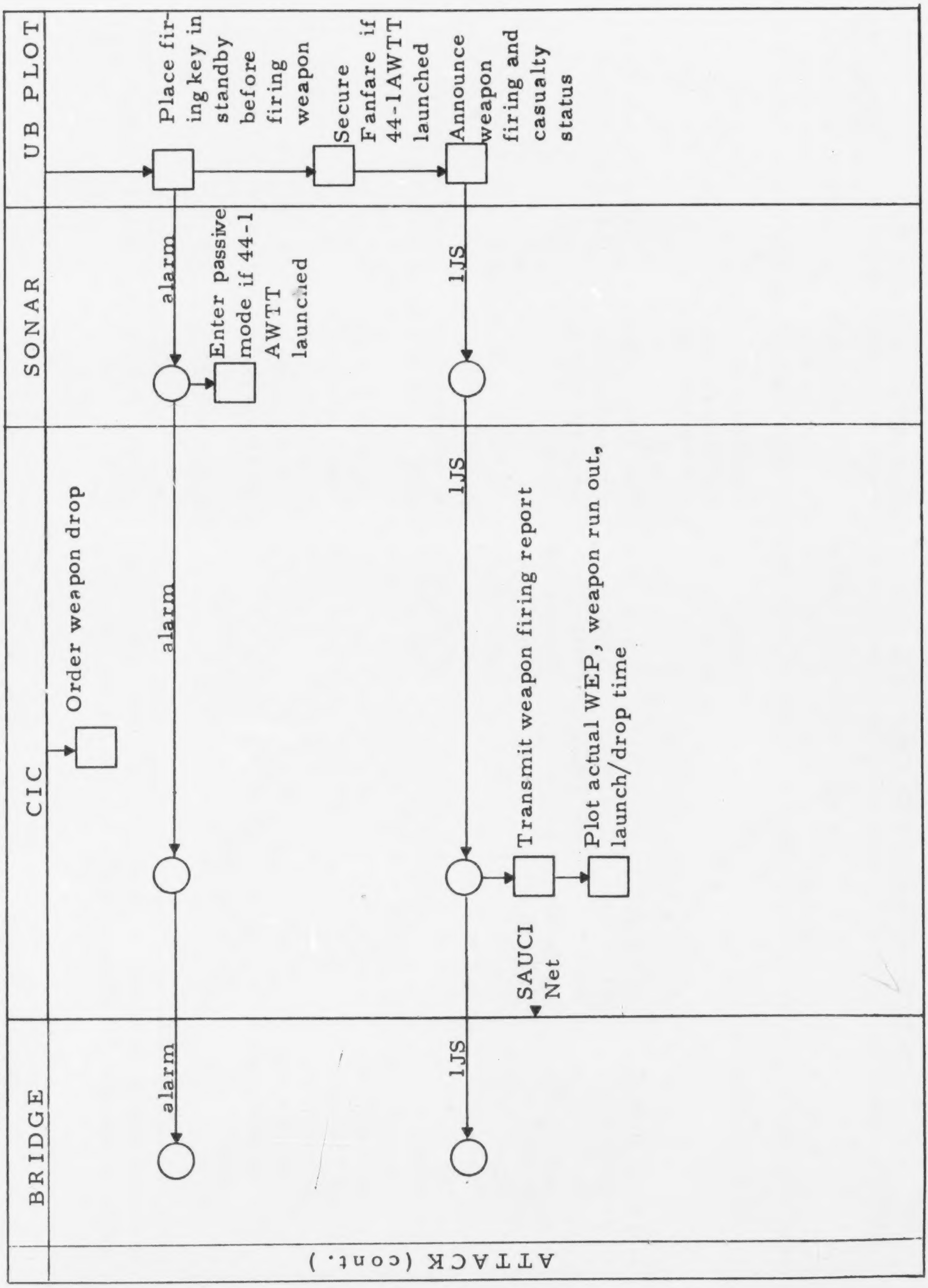
ATTACK (cont.)
BRIDGE
CIC
SONAR
UB PLOT
Order weapon drop
alarm
alarm
alarm
Place firing key in standby before firing weapon
Enter passive mode if 44-1 AWTT launched
Secure Fanfare if 44-1AWTT launched
Announce weapon firing and casualty status
1JS
1JS
1JS
Transmit weapon firing report
Plot actual WEP, weapon run out, launch/drop time
SAUCI Net

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT[1]

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
1. Set-up equipment	All		All	Knowledge of setup operations, procedure following	
2. Initial plotting procedures • plot datum FOPC LLA TDZ DZ TDA Time late to datum ETA at TDA (for determining approach and initial search plan)	North and South plotters, Evaluator, CIC officer	From OTC (over the PRITAC)	NC-2 plotter status boards RT Nets/ownship (Sonar 1JS, Radar 22JS, ECM WLR-1)	Translate reported information into geographic coordinates Decoding procedures (brevity code, scramble table, ASW action table) Compute and plot FOPC via doctrine (every 3 minutes assuming conventional sub and speed) Status board plotting	Communications link (intership)

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[1] We were unable to locate any formally generated task analyses for the 14A2 device, hence the task analyses were accomplished by Dunlap and Associates, Inc.

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
				Compute TDA based on FOPC (doctrine) Knowledge of doctrine Knowledge of own-ship capability and friendly forces	
3. Determine and recommend approach to scene-of-action and initial search area plan, and plans red and black	Evaluator CIC officer	To Bridge to SAU (approach and plan sent to SAU Ships via SAUTAC and monitored by OTC)	NC-2 Plotter publications (ATP-1(A)) NWP 24-C)	Knowledge of own-ship capabilities and friendly forces Knowledge of doctrine Knowledge of search and attack plans in ATP-1(A) (6)	Size of contact area at scene of action (quality of datum) Position of contact area with respect to SAU
• Determine position of datum with respect to SAU				Estimate of submarine mission and intent	
• Compute time late to datum		Bridge orders the approach and steers the ship			

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
• Determine ship separation and speed	(OTC may order approach, red and black plans)				
• Recommend countermeasures					
- weaving (narrow or broad)					
- streaming and activating FANFARE					
- turn count masking					
- degaussing					
4. Recommend search arcs and ranges to Sonar	Evaluator CIC officer	Sonar	NC-2 Plotter	Analysis of contact area geometry Analysis of FOPC and own-ship position	Contact area with respect to SAU

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
5. Plot search plan sectors and assign units to sectors (if PINEAPPLE, 3SH)	Evaluator CIC officer		Maneuvering board NC-2 Plotter	Knowledge of search and attack plans (ATP-1(A)) Estimate of supporting units, tactical sonar ranges of maneuvering capabilities	
6. Plot positions of other units involved in coordinated search					
• ranges and bearings plotted from radar scope	Radar Operator	North Plotter (NC-2)	SPS-10 NC-2 Plotter	Plotting Manipulation of range/bearing cursor and interpret range/bearing readouts (radar)	
• correlate and disseminate SITREPS from other units	Evaluator	Sonar UB/ Plot Bridge	IJS circuit	Knowledge of decoding procedures	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
7. Monitor approach to scene-of-action	North and South plotters, Evaluator, CIC officer	Bridge to SAU	NC-2 Plotter	Analysis of track with respect to datum	Tactical geometry
• recommend maneuvers for own-ship and other units (as required)				Analysis of FOPC	
• entrance into TDA announced					
• recommend optimum sonar speed and appropriate countermeasures					

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
8. Monitor execution of initial search plan and recommend maneuvers	CIC officer, Evaluator	Bridge	NC-2 Plotter, radar (ranges and bearings on other units)	Overall cognizance and assessment of the tactic being developed, employment of the vehicle	
CONTACT					
9. Announcement of Contact	Radarman	Evaluator			
10. Commence target plotting					
• radar - range datum, datum time plotted	South Plotter	Evaluator Plotters	SPS-10, NC-2 Plotter	Manipulate range/bearing cursor and interpret range/bearing readouts	Illumination of target cursor, range capability
• sonar - range and bearing from own-ship plotted every 15 seconds	South Plotter	Standby Sonarman	NC-2 Plotter 61JS	Plotting-translate range/bearing reports into geographic coordinator	Target differentation, range scale settings

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
11. Initial contact report over CI Net (if contact previously lost, regain contact, amplifying report sent over CI Net If contact made by other units (mad contact, dipping helo, other ship sonar) contact information received over RT Nets	CI Net Talker	Evaluator	CI Net Telephone	Translate contact information into message format (plain language/ brevity code or scramble table) and transmit	
12. Determine contact range and bearing clear or foul and report	Surface Sonarman		SPS-10	Interpret radar display (movement of target, relative geometry of force disposition)	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
13. Determine target course and speed and reported frequently over 1JS (always whenever a course, speed change of target)	Evaluator	Sonar	NC-2 Plotter	Determine target aspect from target track relative to own-ship; CIC matches up target aspect with sonar doppler information, and course and speed with UB/Plot target motion analysis (NOTE: This is an iterative process and is the core of the operations from initial contact to firing standby)	
14. Recommend maneuvers to hold contact at maximum possible range	Evaluator CIC officer	Bridge	NC-2 Plotter	Knowledge of: - own-ship tactical sonar range - capabilities of weapon delivery systems (range and accuracy)	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task'	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
				- tactics/doctrine (tactical deception) - maneuvering capability of own-ship and SAU	
15. Make inputs to contact classification/identification based on contact plot (indicated motion-speed and maneuvers shown)	Evaluator	Bridge, Sonar	NC-2 Plotter	Movement analysis-possible submarine (how fast target is moving-nuclear/conventional)	
16. Estimate target threat (deliberate vs. urgent attack requirements)	Evaluator	Bridge, UB/Plot		Assess threat geometry • intelligence information • course/speed/range/bearing information	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
17. Recommend co-ordinated attack plan, Weapon system (AWTT, ASROC, DASH, A/C), and Firing time	Evaluator	Bridge, Plotters	NC-2 Plotter, 1JS	Knowledge of tactics and doctrine (ATP-1)	
				Evaluate assignment geometry (position of own-ship and support units holding contact with respect)	SITREPS from other units
• Specify attack/assist roles for:				Determine relationship of own-ship support units holding contact with respect to target	Plot of own-ship support units, and target
GEO Sector (3A)					
- Sector boundary orientation					
- Sector assignments for ships					
LOCK-ON (1A)					

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TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
-tactical diameter,	Evaluator	Bridge, Plotters	NC-2 Plotter, 1JS, maneuvering board	Make relative motion analyses for own-ship, support units, and target	
-courses and speeds (or rudder, speed, engine orders) for assist ship					
DEEP CREEP (2A)					
-courses and speeds for attack ship	Evaluator	Bridge, Plotters	NC-2 Plotter, 1JS, maneuvering board	Make relative motion analyses for own-ship, support units, and target	
18. Amplifying report stating attack intentions sent over CI Net	CI Net Talker	Evaluator to Bridge	Radio Telephone	Transform plotted information and verbal reports into appropriate message format	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
				ATP 1-A, Vols. I and II for message formats, NC-2 plotters data (target position course and speed)	
19. Recommend and plot appropriate support method (Bear 11A, Redwood 12A, or Fence 13A)	Evaluator	Bridge, Plotters	NC-2 Plotter, 1JS	Evaluate engagement geometry Knowledge of support plans in ATP1-A, Vol. I Estimate of submarine's capabilities and intentions	Plot of own-ship, support units, and target
• If ASROC - plot projected WEP	South Plotter	UB/Plot Radar	SPS-10/WSA-1 system NC-2 Plotter	Plot WEP on NC-2 Plotter from verbal report (Radarman or UB/Plot)	Generation of WEP symbol on SPS-10 Radarman report of range/bearing Report from UB over 1JS (range/bearing to WEP)

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
• Plot ASROC, AWTT, Weapon Firing lane	South Plotter	Evaluator	NC-2 Plotter	Knowledge of safety zones for ASROC/ AWTT (from NWP 24-C)	ASROC projected AWTT firing bearing
20. Announcement made of any ship(s) or A/C endangered by weapon launch, and vectoring recommendations to clear units	Radarman Evaluator	Bridge	NC-2 Plotter SPS-10	Analysis of tactical plot in terms of: Weapon trajectories/runout and acquisition capability Relative motion analysis of units regard vectoring on safe positions	Plot of own-ship, support units and target
21. Weapon warning report sent over CI Net (15 seconds prior to firing)	CI Net Talker	Evaluator, UB/Plot	Radio-Telephone	Transform plotted information (range/ bearing to WEP) verbal information into appropriate message format	ATP-1-A, Vols. I and II for message formats, NC-2 plotter data (range/bearing to WEP). Verbal reports on attack variations.

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
WEAPON LAUNCHED					
22. Plot water entry point weapon runout, and launch (drop) time plotted	South Plotter	Evaluator, Radarman	NC-2 Plotter	Knowledge of weapon characteristics, translate range/bearing reports into NC-2 Plotter coordinates or mark position of green bug	
23. Weapon Firing report sent over CI Net	CI Net Talker	Evaluator Plotters	Radio-telephone, NC-2 Plotter	Transform plotted information and verbal reports into appropriate message format	ATP 1-A, Vols. I and II for message formats. NC-2 Plotter data (WEP, Firing time). 1JS reports from UB
24. Record kept of Weapon Run Time	South Plotter		Clock (stepwatch)	Determine when weapon run time expires based on knowledge of weapon performance characteristics	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
POST ATTACK					
25. Recommend maneuvers to position ship for any reattack	Evaluator, CIC officer	Plotters, Bridge	NC-2 Plotter	Predict target evasive maneuvers. Knowledge of target attack capabilities	
26. Amplifying report sent over CI Net describing attack results and any reattack intentions	CI Net Talker	Bridge, Evaluator, Plotters	Radio-Telephone	Transform plotted information and verbal reports into appropriate message format	ATP-1-A, Vols. I and II for message formats. 1JS reports from UB/Plot
LOST CONTACT					
27. Datum, datum time plotted	South Plotter	Evaluator (Sonar)	NC-2 Plotter, 1JS	Translate range range/bearing report into NC-2 Plotter coordinates	Lost contact report from Sonar (last range/bearing over 1JS
28. Lost contact amplifying report sent over CI Net	CI Net Talker	Evaluator Plotter	Radio-Telephone, NC-2 Plotter	Transform plotted information and verbal reports into appropriate message format	ATP-1-A, Vols. I and II for message formats. NC-2 Plotter data (datum, datum time)

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
29. Recommend lost contact search	Evaluator CIC Officer	Bridge		Knowledge of evasive capability of target Knowledge of lost contact search plans (ATP-1-A)	Range of datum from SAU, ATP-1-A Lost contact plans.
• Acorn (2S) - Datum specified - Right or left plan recommended and plotted - Axis direction - Speed and countermeasures - Follow up search recommended	Evaluator CIC Officer	Bridge	Acorn template NC-2 Plotter	Position template and trace on NC-2 Plotter Knowledge of maneuvering and sensor capabilities of support units	Datum, datum time, target track

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
• Oak Tree (1S) - Datum specified - Ship separation, line of bearing, speed and countermeasures recommended - Follow up search recommended	Evaluator, CIC Officer	Bridge	NC-2 Plotter	Knowledge of maneuvering and sensor capabilities of support units	Datum, datum time, target track own-ship and support units TSR
30. Amplifying report sent over CI Net, describing Lost Contact search intentions (If different from originally stated)	CI Net Talker	Evaluator	Radio-Telephone, NC-2 Plotter	Transform plotted information and verbal reports into appropriate message format	ATP-1-A, Vols. I and II for message formats and Lost Contact search plans NC-2 Plotter data (datum, datum time)
31. Recommend maneuvers to conduct Lost Contact search	Evaluator, CIC officer	Plotters, Bridge	NC-2 Plotter	Knowledge of own-ship maneuvering capabilities	

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
				Predict target evasive maneuvers Knowledge of target attack capabilities	
32. Target course dead reckoned	Plotters		NC-2 Plotter	Project target last known course/speed into predicted track (on NC-2 Plotter)	Last known target course and speed
33. Recommend search arcs/ ranges to Sonar	Evaluator, CIC officer	Plotters, Sonar	NC-2 Plotter	Estimate sub probability area and translate into degrees of search arc and range for Sonar	Sub dead reckoned track, Last known target course and speed
34. EP's announced frequently	Evaluator	Plotters, Sonar	NC-2 Plotter	Read sub position off dead reckoned track periodically	Sub dead reckoned track
TORPEDO EVASION					
35. Torpedo detection report sent over CI Net	CI Net Talker	Evaluator, CIC officer	Radio Telephone		

TABLE 36. ANALYSIS OF CIC TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
36. Recommend evasive maneuvers		Sonar	NC-2 Plotter	Knowledge torpedo evasive factors in ATP-1-A, Vol. I Distinguish between straight running, pattern running and homing torpedoes	Plot of torpedo hydrophone effect bearing, torpedo characteristics reports from Sonar
37. Plot torpedo hydrophone effect bearings and time of initial detection	South Plotter	Evaluator	NC-2 Plotter	Translate bearing reports into plotted bearing lines as NC-2 Plotter	Torpedo hydrophone effects bearings, reports from Sonar (1JS)
38. Torpedo identification made on basis of plot	Evaluator	Plotters, Sonar	NC-2 Plotter 1JS	Based on plot of torpedo hydrophone effects bearings, distinguish between straight runner, pattern runner	Plot of torpedo hydrophone effects bearings, reports from Sonar (1JS)
39. Monitor Run Time of torpedo	South Plotter		Time clock	Monitor elapsed time	Time of initial torpedo detection
40. Probable expiration of torpedo announced	Evaluator	South, Plotter, Bridge	NC-2 Plotter	Knowledge of enemy torpedo characteristics	Time record of enemy torpedo run

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
COMEX					
1. Pick-up procedure carried out and appropriate type control established	ASAC	A/C Pilot, Evaluator	ASW Air Control RT Net	Knowledge of correct voice procedures	A/C call sign, display of A/C on SPS-10/NC-2
• Initial vector to datum given and appropriate MAD trapping circle recommended. (fixed wing aircraft)	ASAC	Plotters, Evaluator, A/C Pilot	SPS-10, NC-2	Derive course/ speed A/C vector to datum from NC-2. Knowledge of F/W A/C tactics (ASAC Handbook, NWP-24-C)	Plot of datum (NC-2), A/C representation on SPS-10/NC-2
2. A/C report received and information passed to Evaluator	ASAC	Evaluator	ASW Air Control RT Net	Translate formatted report into plain language for dissementation. Knowledge of brevity code terms.	A/C report over Air Control Net

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
3. Following information about SAU passed to SAC (Aircraft): • Composition/formation of SAU, position of SAU Cdr, position and callsign of ASW Air Control ship • Position of SAU relative to SAC (passed at reasonable intervals) • SAU ETA at datum • Long range weapons available in SAU	ASAC	Evaluator, Plotters	ASW Air Control RT Net	Working knowledge of report format (ATP 1-A Vols. I and II) and appropriate voice procedures	Information parameter inputs from NC-2 (i.e., ETA at datum)

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
• Initial search plan intentions					
• RED and BLACK plan intentions when SAC					
4. SAC (A/C) report received and information passed to Evaluator	ASAC	Evaluator	ASW Air Control RT Net	Translate formatted report into plain language for dissemination, knowledge of brevity code	SAC (A/C) report over Air Control Net
5. Intentions for SWAP (including time) transmitted to SAC	ASAC	Evaluator	ASW Air Control RT Net	Knowledge of voice procedures and reporting format (ATP 1-A, Vols. I and II) ASAC Handbook	Ordering information from Evaluator
ENTER TDA					
6. SWAP achieved and announced	ASAC	Evaluator	ASW Air Control RT Net	Knowledge of voice procedures and reporting fromat (ATP 1-A, Vols. I and II), ASAC Handbook	Ordering information from Evaluator

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
7. SWAP report received and information passed to Evaluator	ASAC	Evaluator	ASW Air Control RT Net	Translate formatted report into plain language for dissemination. Knowledge of brevity code terms	Report from A/C over Air Control Net
8. Appropriate type control established for initial search	ASAC	Evaluator	ASW Air Control RT Net	Knowledge of voice procedures and reporting format (ATP 1-A, Vols. I and II) ASAC Handbook	Ordering information from Evaluator
9. Orders given for search:					
• (Oak Tree 1SH) Correct voice/vectoring procedures used in positioning helo's in extended search line	ASAC	Evaluator, Plotters	ASW Air Control Net SPS-10/WSA-1, NC-2	Knowledge of headwind, crosswind and tailwind vectoring techniques	TSR's for helo's

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
• (Pineapple 3SH) Correct voice/vectoring procedures used in assigning helo's to sectors			NC-2	Derive HS vectors (course, speed, altitude) and dip positions from display of OS, support units and A/C on SPS-10 or NC-2 knowledge of correct voice procedures	TSR's for helo's
CONTACT					
10. Positive control established with VS A/C (if not done already)	ASAC	Evaluator	ASW Air Control RT Net	Knowledge of voice procedures and reporting format (ATP 1-A, Vols. I and II, ASAC Handbook)	Ordering information from Evaluator
11. Correct vectoring/voice procedures employed during MADVEC	ASAC	Evaluator, Plotters	ASW Air Control, RT Net SPS-10 WSA-1 NC-2	Knowledge of correct voice procedures. Derive VS vectors/course, speed altitude) from display of OS, support units and target on SPS-10/WSA-1 or NC-2	Target and A/C symbols displayed on SPS-10/WSA-1 or NC-2

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
12. Successful MADVEC announced	ASAC Plotters	Evaluator, Plotters	ASW Air Control RT Net SPS-10/ WSA-1 NC-2	Mark position of A/C MADMAN on SPS-10 or NC-2, determine range/ bearing (use of R/b cursor on SPS-10) from OS and announce	Representation of OS support units, A/C, and target on SPS-10 or NC-2
ATTACK					
13. Appropriate support method ordered:					
• (Fence 13AH) helo's assigned to appropriate sectors	ASAC	Evaluator	ASW Air Control RT Net NC-2, SPS-10	Knowledge of support plans and ordering procedures in ATP 1-A, Vol. I.	Ordering information from Evaluator, TSR's of helo's, SAU attack plan
• (Bear 11AH) Range/bearing of helo dip line ordered				Translate plotted information (position of support units, target) into ordering information for helo's	

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
14. For ASROC, any A/C endangered by ASROC shot, vectored clear of impact area	ASAC	Evaluator	ASW Air Control RT Net NC-2, SPS-10	Determine A/C salvo vector from NC-2 plot	Firing bearing zones from NC-2
WEAPON LAUNCH					
15. DASH vectored to drop points expeditiously	ASAC or DASH controller	Evaluator	DASH Control unit SPS-10 or NC-2	Determine and insert course, speed, altitude value to drone, based on display of drone target OS and support units on NC-2 or SPS-10	Display of drone, target, WEP, OS and appropriate units on NC-2 or SPS-10
16. A/C vectored to drop point(s) expeditiously, employing correct voice procedures	ASAC	Evaluator	ASW Air Control Net SPS-10 or NC-2	Knowledge of correct voice procedure. Derive A/C vectors (heading, speed, altitude, turn rate) from display of OS support units, target, and A/C on NC-2 or SPS-10	Display of A/C, target, WEP, OS and support units on NC-2 or SPS-10

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
17. A/C vectored to appropriate holding pattern following weapon drop					
LOST CONTACT					
18. Appropriate lost contact search ordered:					
• Acorn (2SH)	ASAC	Evaluator	ASW Air Control Net SPS-10 or NC-2	Knowledge of lost contact plans in ATP 1-A (DD and HS, F/W air plans, MAD traps, etc.)	Ordering information from Evaluator regarding coordinated lost contact
- Helo's vectored to dips 1 and 2				Derive A/C vectoring information from tactical plot	Target plot information to include datum position and time, previous and DR's target track OS and support units

TABLE 37. ANALYSIS OF CIC TASKS IN SAU AIR CONTROL (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
- Follow-up search intentions stated					
• Oak Tree (1SH)					
- Helo vectored to dip positions in extended search line				Knowledge of correct voice procedures in giving ordered information	
- Follow-up search intentions stated					

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
COMEX					
1. Determine predicted sonar ranges (PSR's) for periscope depth and best depth; develop ray path plot or use range tables	Sonar Supervisor	Other ST's	Appropriate plotting materials NAVPERS 900.196	Interpretation of BT information from traces on BT slide Translate BT information into plot of expected ray paths; or determine sonar performance figures and look up ranges in NAVPERS 900.196	Latest BT information, plotting materials, NAVPERS 900.196, Manual for Estimating Echo Range
2. Implement any ordered procedures to prevent mutual interference	Sonar Operator	Sonar Supervisor	Sonar stack use of Sector Width control	Set in ordered sector value	Search orders via 1JS
3. Sweep any search arcs recommended by CIC or implement "beam to beam" search procedures	Sonar Operator	Sonar Supervisor	Sonar stack, use of range/bearing cursor	Position cursor in 5 to 10 degree increments through arc to be searched	Recommendations for search via 1JS. Representation of cursor on PPI, controllable in range and bearing

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
4. Vary keying intervals (range scales) according to PSR's, vary pulse length, depression angle (if high sea state or expect contact to be deep), mode video, and "ride" gain control for each ping.	Sonar Operator	Sonar Supervisor	Sonar stack, use of RANGE SELECTOR, PULSE LENGTH, DEPRESSION ANGLE, MODE SELECTOR, VIDEO, and MASTER LEVEL controls.	Develop and employ a strategy of control manipulation appropriate to the current environmental/ tactical situation to enhance chances for detection. Knowledge of Random Keying Plan DELTA and other search doctrine (NWP-24(C), NAVPERS 10131, Sonarman 3&2, NAVPERS 10140 Sonar Technician 1 & Chief).	Functional control features affecting PPI/ Audio displays as enumerated in "Equipment" column.
5. Implement any orders regarding deployment of material countermeasures (streaming/activating FANFARE)	Sonar Technician	Sonar Supervisor	FANFARE Control Unit; use of POWER Control	Implementation material countermeasure orders via FANFARE unit (proper use of POWER Control)	Countermeasure orders via 1JS. Functional features of FANFARE Control Unit

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
CONTACT					
6. Detect/announce initial contact	Sonar Operator	Sonar Supervisor, Standby Sonar Operator	Sonar stack (range bearing cursor. PPI readouts) 29MC circuit	Distinguish valid from false contact, using combined audio/video presentation. Knowledge of initial contact reporting format	"Realistic" representation of a valid sonar contact (as well as a background of false contacts from which to distinguish it), having appropriate audio and video properties (echo quality, doppler, echo strength, blip shape) Current sonar contact range and bearing readouts
7. Enter "contact" mode	Sonar Operator		Sonar stack, use of DIRECTOR CONTROL function	Knowledge of proper use of DIRECTOR CONTROL function	

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
8. Determine/ announce initial contact classification (with level of confidence), and revise as necessary	Sonar Supervisor	Sonar Operator	Sonar stack, 1JS, S.P. Telephone	Distinguish a submarine contact from a non-submarine contact (natural, submarine launched decoys) using both audio and video presentations	Realistic representation of a submarine contact (as well as periodic non-submarine contacts from which to distinguish it) having appropriate audio and video properties (echo quality, doppler, echo strength blip size) to include submarine generated (nuclear) noise spokes having appropriate audio and video characteristics
9. Continue to track target, provide current range and bearing information	Sonar Operator Standby Sonar Operator	Sonar Supervisor	Sonar stack, use of range/bearing cursor 61JS, S.P. Telephone	Psychomotor coordination involved in the manipulation of q Ra and q Bya handwheels to	Dynamic real-time representation of target position (to include selective motion components of target

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
				smoothly position the end of the cursor (adjustable in range and bearing) on target position for each ping	vehicle and ownship for PPI display); display of range/bearing cursor, adjustable in range and bearing
				Knowledge of reporting format and cycle time for current target range and bearing	Current sonar contact range and bearing readouts
10. Determine and announce target aspect periodically, always when a change is detected	Sonar Supervisor	Sonar Operator	Sonar stack, 1JS S.P. Telephone	Discriminate pitch changes (audio), up (bow), no (beam), down (stern) and identify blip shape (PPI video) as indicative of target aspect	A correlated display of doppler (audio) and video blip shape that corresponds to target aspect at any given time

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TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
ATTACK					
11. Accept aided tracking (Director Control) from UB/Plot to position cursor (assuming a "smooth" fire control solution has developed)	Sonar Operator	Sonar Supervisor	Sonar stack, use of DIRECTOR CONTROL function	Knowledge of proper use DIRECTOR CONTROL function	Aided tracking inputs via hard wire connection from attack director, functional properties of DIRECTOR CONTROL
POST ATTACK					
12. (Mk 44-1 AWTT) Employ passive mode for X seconds following weapon launch	Sonar Operator		Sonar stack, use of RANGE SELECTOR function	Position RANGE SELECTOR function on "LISTEN" following weapon launch	RANGE SELECTOR control with "LISTEN" capability (passive mode)
13. (Mk 44-1 AWTT) Secure FANFARE for X minutes following weapon launch	Sonar Technician		FANFARE Control Unit, use of POWER control	Proper use of POWER control	Functional control features of FANFARE Control Unit

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
LOST CONTACT					
14. "No echoes" reported, and appropriate no echoes procedures (slewing) carried out	Sonar Operator	Sonar Supervisor Standby Sonar Operator	Sonar stack, use of cursor 1JS and 61JS Sound Powered telephones	Detect loss of contact, and implement proper slewing and reporting procedures according to doctrine (NWP 24-C) prior to declaring "lost contact"	Capability for denying sonar contact in a realistic manner
15. "Lost Contact" announced, with last range and bearing; request search arcs from CIC	Sonar Supervisor	Sonar Operator	1JS, 61JS S.P. Telephones	Knowledge of proper lost contact reporting procedures (NWP 24-C) to implement following unsuccessful "no echoes" procedures; proper slewing procedures to implement while waiting for search arc	

TABLE 38. ANALYSIS OF SONAR TASKS IN SAU MISSION CONTEXT (Continued)

Task	Operator	Coordination With	Equipment Involved	Skills and Knowledges	Information and Simulation Requirements
16. Sweep search arcs recommended from CIC	Sonar Operator	Sonar Supervisor	Sonar stack, use of cursor ($q^{(Ra)}$ and $q^{(Bya)}$ handwheels) 1JS S.P. Telephone	Knowledge of proper procedures (NWP 24-C) for searching recommended arc with cursor. (Size and direction of increments)	Search arc recommendations via 1JS Representation of cursor on PPI, controllable in range and bearing
17. Detect, classify, and report torpedo hydrophone effects (H/E) - announce latest bearing and any bearing-drift	Sonar Operator	Sonar Supervisor Standby Sonar Operator	Sonar stack, 29 MC 1JS, 61JS S.P. Telephone	Ability to detect and correctly classify H/E as generated by a torpedo. Knowledge of appropriate torpedo H/E	Generation of torpedo hydrophone effect noise spoke have appropriate audio/video characteristics, and with display dynamics corresponding to motion of torpedo relative to OS.

4.3.1.1 Task Structure Summary. The task activities for device 14A2 training emphasize skills and knowledges dealing with individual and team procedures and with decision-making behavior. A premium is placed on the following skill and knowledge requirements:

- Knowledge of ASW procedures in operating individual equipment components and in subteam procedures in employing the ASW platform.
- Knowledge of ASW doctrine (procedures and tactics) as prescribed in official Navy publications (e.g., NWP-24C, ATP-1-(A), Vols. I, II, ATP-28, ASAC handbook, etc.).
- Procedural skills in operating equipments in the CIC, UB/Plot and Sonar compartments.
- Heavy requirements on team interaction and coordination, vis-a-vis internal and external communications and decision-making activities.
- Information plotting (e.g., NC-2 Plotter, DRT, status boards).
- Information processing--formatting requirements, (brevity codes, scramble tables; preparing information for dissemination based on own-ship sensor performance).
- Visual-perceptual demands--emphasis on display interpretation (e.g., sonar, and attack director in achieving fire control solutions; radar) and display monitoring (e.g., displays of ship control equipments, NC-2 Plotter, radar, sonar).

Limited requirements are placed on manual control skills. Manual control requirements are most prominent in the control of DASH and in cursor manipulation in Sonar, Radar and Attack Director (UB/Plot).

Vehicle control requirements are minimal. Steering the ship from the bridge (ordered speed, rudder angle, and course) is accomplished simply via a potentiometer control rather than with the controls found aboard ship.

4.3.2 Training Objectives. The training objectives reflect a variety of team training situations ranging from drills on basic attack procedures through complex situations involving coordinated multi-unit operations to cover the cross-section of ASW operations in a "hot war" environment. The training objectives provide the inputs for identifying design capabilities that must be present in the device in order to accomplish the training deemed necessary. The training objectives point up also the flexibility needed in device capabilities to enable the instructor staff to select exercises for training according to:

- Team skill level upon entering training
- Team learning rate during a training session
- Time available for training
- Specific training desired by a team (e.g., preparation for an upcoming fleet exercise).

Several levels of team training are envisaged, each having specific and well-defined training objectives. These levels, described next, represent a build-up of exercise difficulty and provide the rudiments for an instructional package beginning with the entry level of a team and progressing through advanced ASW tactical employment of own-ship in a SAU context.

4.3.2.1 Basic Attack Exercises. These represent initial training exercises and cover the basic attack procedures associated with own-ship weapons systems. The team is required to practice developing fire control solutions and launching the weapons they possess against targets they have searched for and detected. Exercises start with an undetected target, followed by early detection. The team briefing prior to the exercise instructs the team to develop a fire control solution and to launch the weapon designated in the exercise as rapidly and accurately as possible. The exercises use the one-destroyer (own-ship) versus one-submarine situation. Exercises should be provided which specify ASROC, AWTT, DASH, RTDC (nuclear) and HS/VECTAC attacks.

The training objectives stress the fundamentals of ASW operations in subteam and team performance. They center on the development of coordinated procedures and internal communications in achieving fire control solutions and launch of the available weapons systems. In addition, the team is exposed to basic submarine tactics, torpedo hydrophone effects, equipment casualty and the geometric aspects of threat, including maneuvering for attack and lost contact procedures. The specific concerns include:

- Equipment setup and checkout procedures in the subteam compartments

- Appropriate utilization of internal communication circuits
- Procedures in search and detection
- Procedures for readying weapons systems for attack
- Prosecution of targets.

4.3.2.1.1 Training Objectives. Conduct accurate and timely ASROC attacks and AWTT attacks using Mk 44 and Mk 46 torpedoes against straight running and maneuvering targets at various ranges and courses relative to own-ship. Implement standard procedures for search, detection, fire control and launch. Implement lost contact procedures.

Sonar

- Conduct standard no echo and sector searches
- Provide timely detection and target status reports
- Track targets accurately including difference and director modes
- Employ post attack doctrine for Mk 44-1 torpedo.

UB Plot

- Perform target motion analysis
- Conduct weapon selection and launch sequence
- Monitor/recommend ship control during attack
- Identify and rectify malfunctions.

CIC

- Monitor/recommend sonar search
- Monitor/recommend ship control
- Monitor/verify fire control solutions
- Implement tactical deception techniques
- Plot own-ship target and weapon positions
- Implement torpedo evasion tactics.

LCCS

- Monitor weapon launch sequence
- Take corrective action when malfunction occurs.

CONN

- Monitor fire control solution (ASROC) and approve weapon selection
- CONN ship to retain contact, minimize vulnerability, conduct attack at standoff ranges.

4.3.2.2 Training in Screening Operations. These are more difficult exercises in which the team performs ASW operations where the mission is to protect a screened unit. The purpose is to develop an understanding of imminent threat to units in the formation and the requirements for rapid response to this threat. The training situations require quick employment of various weapons systems from the screen position with minimal maneuvering after contact. The weapons systems include ASROC, AWTT and aircraft already under positive or advisory control. Weapon launches must be safely accomplished in the presence of other friendly units.

4.3.2.2.1 Training Objectives

- Introduce the team to the principles and procedures of screening to include: crossover patrol of a harbor entrance and shallow water operations, station-keeping in a sector screen, screening other units by means of a bentline screen, screen penetration by submarine, station-keeping in a sector screen about a harbor entrance, shallow water procedures.
- Establish and maintain positive control over aircraft, demonstrate advisory/positive control of HS or VS Aircraft in sector screen stations.
- Introduce the team to coordinated search and attack.
- Conduct urgent or quick attacks from Condition 1AS and Condition II on targets of immediate threat to the force using the best available weapon system.

Specific requirements within these overall objectives include the following:

- Accomplish external reporting procedures to the OTC (including initial Contact reports, Amplifying reports, Warning reports and Firing reports, via plain language, brevity code and the scramble table).
- Compute and plot all information relevant to screening operations (Torpedo Danger Zone, Danger Zone, Limiting Lines of Approach, submarine's most dangerous cone of courses).
- Employ sonar in the situation where mutual interference occurs among units.

- Conduct urgent attacks on targets of immediate threat to the force.
- Achieve VECTACs with aircraft already under positive control in sector screen stations.
- Employ weapons including weapon selection, decisions on when to fire, and reattack.
- Continue training in the development of fire control solutions and launch procedures (but now in the presence of friendly units).

4.3.2.3 Training in SAU Operations. Training in SAU operations where the team is in control of surface and/or airborne units is the most complex and difficult level of operations and involves sequences whereby the team applies the procedures and doctrine in coordinated approach to the scene-of-action, and coordinated search and attack. The exercises present the fundamentals that will prepare a team to better handle the inevitable variations in coordinated search and attack operations that can occur in the ASW environment.

4.3.2.3.1 Training Objectives. Implement the following activities and dependent supporting procedures in conducting single and multiple weapons attack in coordinated SAU operations against conventional/nuclear submarines of various characteristics (speed, depth, maneuvering) in various ocean environments.

- Execute procedures in approach to the scene-of-action. This includes the selection/implementation of approach, countermeasures employment and steering.
- Achieve computation and plotting requirements (CPA to Datum, ETA to TDA, Time Late to Datum, Furthest-on-Position Circle, Weapon Firing Lanes.
- Develop/implement coordinated search plans at the scene-of-action. This includes area, intercept, and lost contact search plan procedures (e.g., OAK TREE variations, ACORN (lost contact), PINEAPPLE).
- Develop/implement coordinated attack plans and procedures at the scene-of-action (e.g., Geo-Sector, Lock-on, Deep-Creep plans; ASROC, AWTT, DASH, Helicopter and fixed-wing VECTACS; own-ship and assist ship interactions; single or multiple weapons attack and reattack).

- Conduct reporting procedures between own-ship and the OTC (SAU CI and PRITAC Nets) including Contact reports, Amplifying reports, and Weapon Warning and Firing reports; and reporting procedures between own-ship and support units (SAUTAC Net).

4.4 GROSS DEVICE DEFINITION. The boundaries of device 14A2 can now be defined in terms of gross hardware orientation. This centers on the trainee compartment requirements and represents the correlation between that piece of the operational universe to be simulated and the ASW operational environment.

4.4.1 ASW Equipment Requirements for Device 14A2

a. Underwater Battery Plot and Sonar

- Mk 53 Attack Console (Mk 114 FCS)
- Mk 38 Attack Console (Mk 111 FCS) (for ships having this system; note--the Mk 111FCS is in the 14A2A; it is not in the 14A2B)
- Mk 143 Position Keeper Computer
- AN/SQS-23 Sonar
- Torpedo Countermeasure Equipment (Fanfare)
- Ship's instruments
- Communication equipment

b. Combat Information Center

- NC-2 Plotting System

- Dead Reckoning Tracer Mk 6
- Radar Plan Position Indicators (2)
- DASH controller station
- Plotting and status boards
- AN/WSA-1 control equipment
- Ships' Instruments
- Communication equipment

c. Conning Station

- Own-Ship Helm
- Radar plan position indicator
- Position indicator Mk 78
- Ship's instruments
- Communication equipment

d. Launcher Captain's Control Station

- Launcher Captain's Control Panel Mk 199
- Relay Transmitter Mk 43
- Communication equipment

4.4.2 Overall Device Layout. The overall layout of the compartments comprising the device is shown in Figure 47. The block layout of the major equipment complexes for UB/Plot-Sonar, CIC, LCCS, and the Bridge are shown in Figures 48, 49 and 50.

4.4.3 Operational Units and the Tactical Area Employed. Eight vehicle units are provided to handle the range of complex tactical situations involved in screen and SAU operations. These are:

- Own-ship
- Support vehicle 1
- Support vehicle 2 (Note: a support vehicle may be used as an assist ship in a 2-destroyer SAU operation; two support vehicles may be used as destroyers in a screen in support of own-ship)
- Aircraft 1
- Aircraft 2
- Aircraft 3 (Note: 1 aircraft unit is employed as DASH where applicable)

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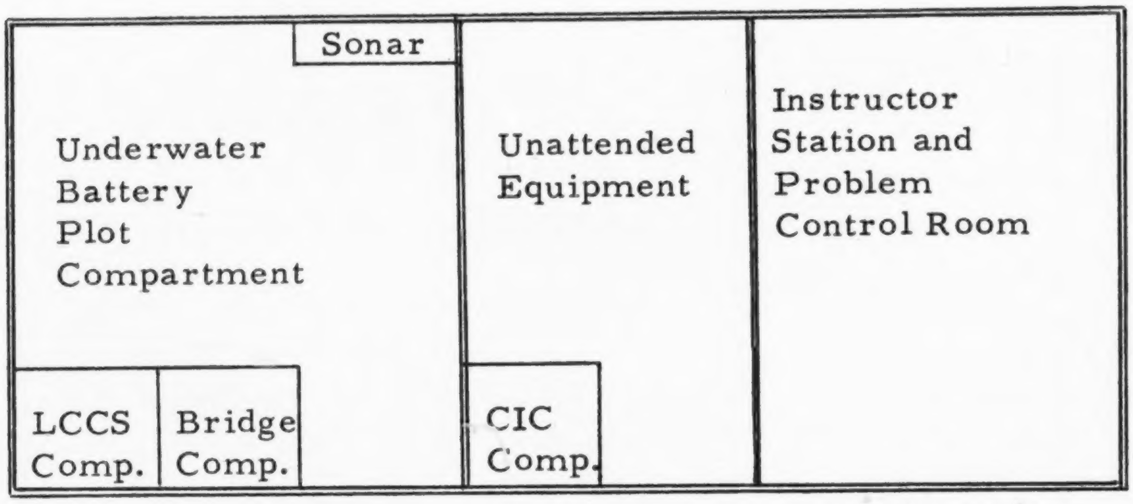
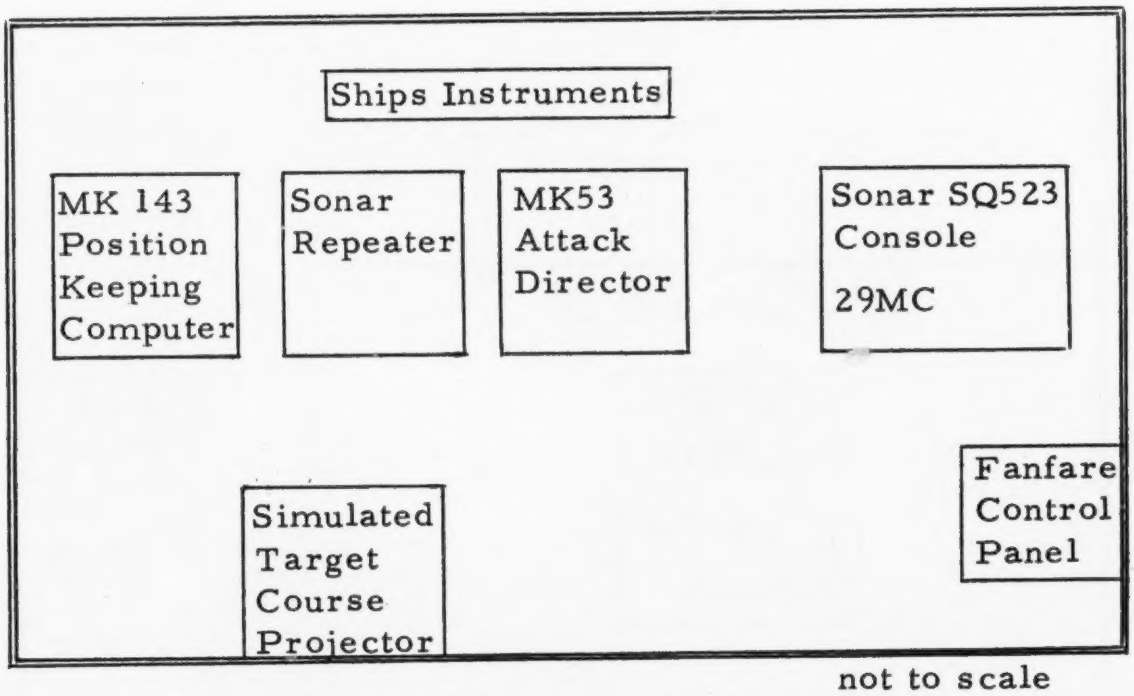
[1] Based on the "Operator's Guide for Surface Ship ASW Attack Training Device 14A2B," NAVSO P3169 (U), U.S. Naval Training Device Center, Orlando, Florida, July 1968 (Conf.)


Sonar
Underwater Battery Plot Compartment
Unattended Equipment
Instructor Station and Problem Control Room
LCCS Comp.
Bridge Comp.
CIC Comp.

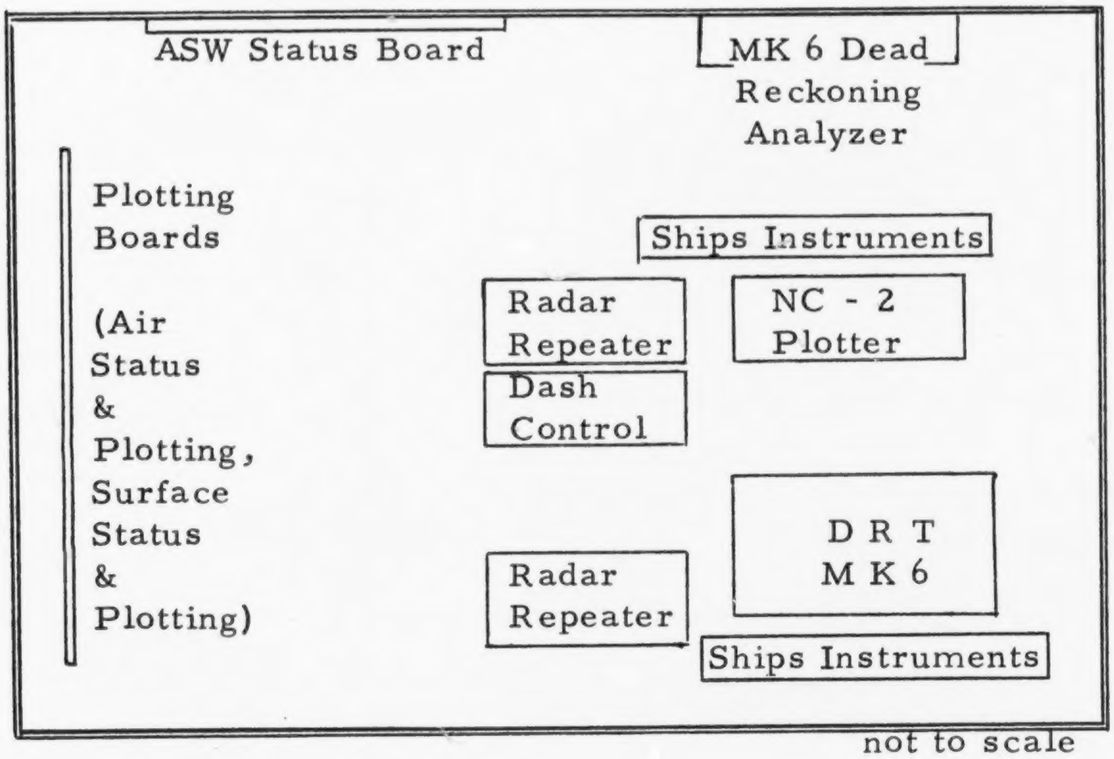
not to scale

Figure 47. Overall Device Layout Device 14A2


Ships Instruments
MK 143 Position Keeping Computer
Sonar Repeater
MK53 Attack Director
Sonar SQ523 Console
29MC
Simulated Target Course Projector
Fanfare Control Panel

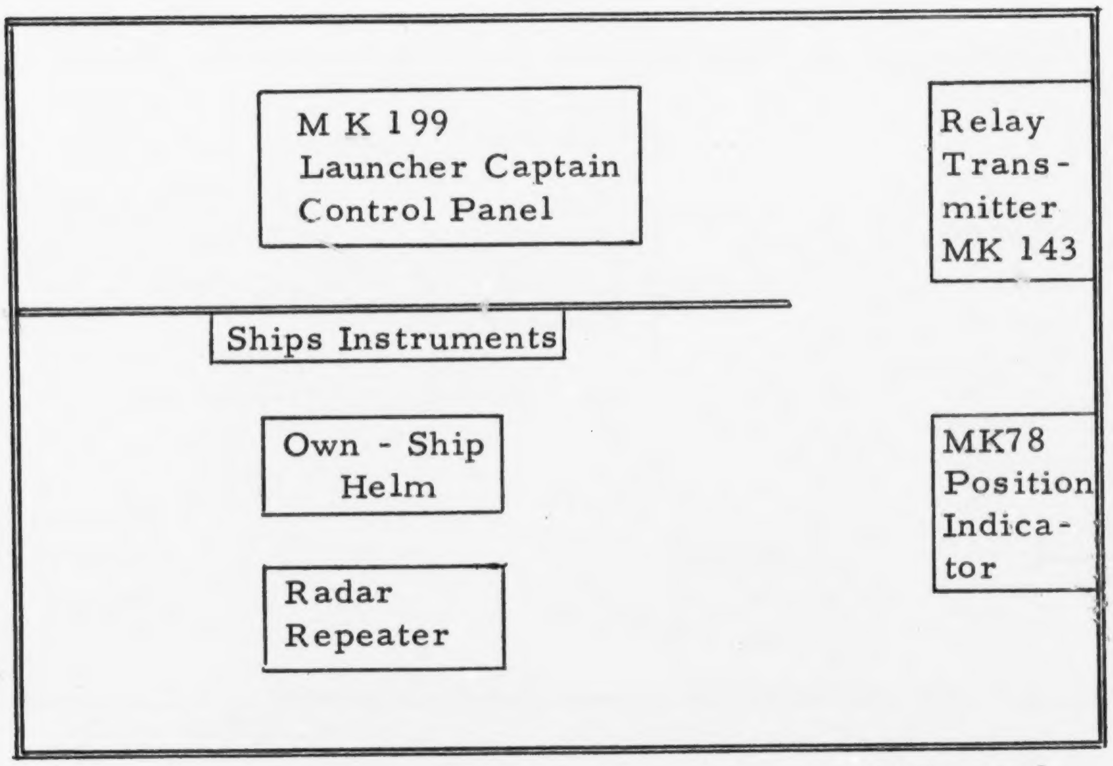
not to scale

Figure 48. Underwater Battery Plot and Sonar


ASW Status Board
MK 6 Dead Reckoning Analyzer
Plotting Boards (Air Status & Plotting, Surface Status & Plotting)
Ships Instruments
Radar Repeater
NC - 2 Plotter
Dash Control
DRT MK 6
Radar Repeater
Ships Instruments

not to scale

Figure 49. Combat Information Center


MK 199 Launcher Captain Control Panel
Relay Trans-mitter MK 143
Ships Instruments
Own - Ship Helm
MK78 Position Indica-tor
Radar Repeater

not to scale

Figure 50. Launcher Captain Control Station (LCCS) and Bridge/Conning Station

- Submarine 1
- Submarine 2 (Note: submarine 2 may be used as an aircraft carrier in applicable missions)

The tactical area of the engagement ranges from a 32 x 32 mile area to a 256 x 256 mile area in the following increments:

32 x 32 miles
64 x 64 miles
128 x 128 miles
256 x 256 miles

4.4.4 Characteristics of the Trainee Population. Each team in the 14A2 is composed of trainees that are members of an ASROC ship's ASW complement. It is assumed that each team member is already qualified in the billet for the training (note: while this is not operationally feasible in every instance, the attempt is made to send trainees qualified in the billets to the 14A2 device).

4.4.5 Scheduling of Training. The flexibility of the device to provide a wide variety of ASW tactical situations makes it admirably suited to a course of instruction ranging from relatively simple one-destroyer on one-submarine procedural team training (detection, fire control solution, weapon selection and launch) through complex multi-unit search and attack operations (SAU contexts). Thus, a complete course of instruction, employing a series of training exercises graduated in difficulty may be accomplished.[1] (Note: At present, teams are scheduled for 14A2 training when the ship is in port. The most prevalent schedule is for each ship to send a team for two consecutive days of training, once every three months).

4.4.6 Output. The 14A2 training system in its gross specifications is firmed up at this point, and from here, the detailed characteristics of the operational environment to be simulated for training are developed. In the normal scheme of development, the process of defining the device characteristics is iterative, beginning with the gross outline of the training system and continuing in refinement and modification as additional technical and administrative inputs are organized, until the functional description of the training device is complete.

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[1] A Utilization Guide for 14A2 team training is presently in existence: Dunlap and Associates, Inc., "Device 14A2 Series Utilization Guide for Surface Ship ASW Attack Team Training." (U), Four Volumes, BSD 69-710, May 1969. (Conf.)

4.5 CHARACTERISTICS OF THE OPERATIONAL ENVIRONMENT TO SIMULATE FOR TRAINING. The analyses thus far have provided the basis for defining that portion of the operational system to be simulated and organized as a training system. A number of key decisions have been made:

- Purpose of the 14A2 training device articulated and the simulation requirements described.
- Training objectives identified and organized.
- Task structure defined and organized.
- Equipment complexes identified and the fixed components set forth.
- Overall training system and operational modes roughed out.

The effort now concentrates on selecting the design alternatives which will define the manner in which the synthetic environment for training will be provided and how the shaping of team learning (structure and control of training) will be accomplished. The human factors contribution to design embraces two distinct phases: 1) the fidelity of simulation issues in representing the operational environment in the trainee compartments, and 2) the management of training which concerns the structuring, controlling and monitoring of training at the instructor station.

> Note: How the device was finally configured (e.g., Device 14A2A, 14A2B) is well known in its details. What we will do here is highlight the points for decision within the two quite different but interrelated categories of trainee compartment and instructor station to reflect the design options that have human factors implications and affect training capability.

4.5.1 Representing the Operational Environment in the Trainee Compartments. So far as organizing the environment in which the learning will take place is concerned, the central issue is, fidelity of simulation. For human factors, fidelity has meaning in terms of the training process and the realism necessary to promote transfer of training. Defining the design characteristics for maximizing transfer of training from the synthetic environment revolves essentially about two interrelated questions: what/how much should be simulated? and how well should this be represented?

Trainee station design considers must prominently the issues involved in achieving simulation fidelity, that is, specifying the hardware (displays/controls) involved in the device and the fidelity levels required at the man-machine interfaces, ranging from high fidelity in engineering simulation to deliberate departures from realism involving special features of design not found in the operational system, in order to enhance learning

To place trainee compartment design in perspective, the range of human factors issues and design alternatives are subsumed under two major categories:

- Configuration of the synthetic system
- Simulation elements and fidelity of simulation

4.5.1.1 Synthetic System Configuration. The job at this point is to flesh-out the system components involved in the trainee station. The need for specific simulation capabilities is now explored based on the groundwork laid in the previous phases. To be resolved, are those portions of the subsystems that must be represented that significantly affect training capability. Decisions are made on the "core" equipments needed to operate analogous to the real world. What instruments/equipments are operable replicas, what are operable but non-replicas and what are non-operable replicas depend on training purpose.

The fleshing out (i.e., defining what is to be simulated) of the configuration is described in the following.

4.5.1.1.1 Government Furnished Equipment vs. Simulated Equipment. The decision to use government furnished equipment vs. simulated equipment, is for the most part, an engineering issue, affected by availability of the equipment, maintenance considerations and budget/cost factors.

The decision was made to simulate all equipments except the plotting equipment (NC-2, DRT) and the DASH Control Console. Since direct transfer of training is required from 14A2 equipment to actual shipboard equipment and procedural competency in operating the equipments is an initial requirement, the physical appearances of equipments with all operating controls and indicators shall be the same for the following:

- AN/SQS-23 sonar
- Attack director consoles (Mk 53, Mk 38 (as required))
- Mk 143 position keeper console
- Mk 78 position indicator
- Mk 199 Launcher Captain Control panel
- Ship control equipments

The radar repeaters are not replicas of the operational radar. The rationale for this is discussed in Section 4.5.1.2.2.

Communication circuits are required as in the operational environment.

- Intercom--(21 MC, 27 MC, 29 MC)
- Sound-powered telephone (1JS, JA, JC, 61JS, 21JS, 8JP, 5JV)
- RT Nets (PRITAC, SAUTAC, screen common, SAU CI, ASW common, ASW Air Control Net).

4.5.1.1.2 Real-World Visual Attachments. There is no requirement for outside-the-platform real-world visual representation. Visual requirements pertain only to electronic displays.

4.5.1.1.3 Platform Motion. There is no requirement for platform motion since the training emphasis is on instruction in ASW team procedures and tactics in CIC, UB/Plot Sonar and the Bridge. The Manual Control requirement (controlling the ship from the Bridge) serves only to ensure that own-ship is positioned as ordered in the tactical environment; training in steering the vehicle is not a training objective.

4.5.1.1.4 Sonar Classification Simulation. A significant design option desirable for the 14A2, concerns the simulation of the parameters permitting the target classification task in sonar operations. The target classification capability is not represented in the 14A2. The plausible reasons for omitting this crucial aspect of ASW are presumably tied in with initial concepts regarding the training purpose of the device and savings in money vis-a-vis the initial ideas about the purpose of the training (particularly since Device 14A6 serves as a coordinated ASW tactical trainer). It seems that the device was initially viewed as an early attack weapon system trainer in which the procedures and doctrine involved in achieving fire control solutions and launches for ASROC, AWTT and DASH were paramount. This emphasis placed on honing team coordination in the procedures and operations associated with target detection, fire control solution and weapon launch would make plausible the decision to omit the classification capability in sonar in view of the engineering problems and associated costs.

But the omission of the classification function interferes with realizing the full potential of the device, all other things being equal. Classification (false target capability) introduces the element of uncertainty in threat evaluation requiring decisions for dealing with false targets and false contacts and the attendant time losses in determining if the contact is a possible submarine. Lack of classification uncertainty also modifies team procedures away from the realism of real-world operations. Currently, the operations in the device from contact through fire control solution and launch, notwithstanding the need for procedural adequacy, makes the process more mechanical than desired. The presence of classification cues forces a greater decision-making requirement on the team and greater tactical involvement reflected in more difficult training exercises, e.g., increased interactions among own-ship personnel and between own-ship and other units. Sonar subteam skills are also enhanced due to the greater whole-task replication in the device resulting in increased involvement and responsibilities for sonarmen.

Achieving the false target capability requires the following classification cues beyond what is currently in device design.

- Own-ship wakes and knuckles
- Vehicle size or aspect
- Submarine knuckles
- Non-submarine returns--(submarine generated) launched decoys, false target cannisters, jammers (NEA beacon)
- Non-submarine returns--(natural) phenomena such as whales, schools of fish, reefs, wrecks, pinnacles.

4.5.1.1.5 Cost Considerations Influencing the Design of Device 14A2. The specification of design for a training system must account for the issue of costs vs. training benefits. Tradeoff analyses are required to put into perspective the training value vis-a-vis increased operational capability afforded by a design alternative per dollar spent. Thus, cost is an important determinant in any ultimate design.

We were unable to assemble a cogent story on cost-effectiveness tradeoff considerations for device 14A2, hence this issue is not discussed here. The importance of cost vs. training value analyses in any design process is, however, emphasized.

4.5.1.2 Simulation Elements. With the configuration of the device set, the issues of specifying those parameters which define "how well" simulation is achieved, are resolved. Specifying the fidelity of simulation is the crucial requirement in representing the synthetic environment in which training is conducted. The human factors input concerns the definition of the simulation elements. These represent, in hardware terms, the parameters and their values (range, envelope, number) needed to accomplish the desired training, hence govern the range and complexity of task installation in the device. The simulation elements which are controllable (manipulated manually via the instructor station) determine the perceptual equivalence of the training environment and the operational situation. The ability to provide the desired training in the identified tasks is directly dependent on the availability and adequacy of these simulation elements in a training device (i.e., which ones are selected and how usefully they are represented). Shortcomings in the simulation of these elements define the shortcomings in the training capability of a device (i.e., simulation elements are associated with the representativeness/complexity of the tasks to be trained in the device).

Adequate specification of these elements is required so as to insure that training purpose and training objectives are achieved (thereby enhancing the transfer of training potential). Since these elements are manipulatible, they also affect the excellence of the utilization context for the sequencing of training (again, in terms of purpose and training objectives). In short, the simulation elements define what is needed in the task environment to achieve the expected transfer of training, assuming effective utilization of the device.

These controllable elements refer to the training mission environment at the trainee compartments and narrow down to three major groupings of characteristics: own-vehicle and support units; submarine targets; and the media.

4.5.1.2.1 Levels of Fidelity. Five levels of simulation fidelity are pertinent to the human factors specification of the characteristics required to insure effective task installation for the 14A2 device. How well each simulation element is to be represented for training should be evaluated in terms of these five levels or dimensions. Table 39 describes the fidelity of simulation levels used in evaluating each of the simulation elements identified. For Level 1, the decision is to either select or exclude the element from simulation. Based on the decision to represent an element in design, the following dimensions are examined to determine the fidelity required to be useful for training. For Level 2, the decision is to select the required value(s) for the element (for example, six levels of sea state for sonar operations); for Level 3, the decision is in terms of engineering precision (for example, sonar signals); for Level 4, the decision is in terms of a necessary reduction in tolerances, or a backing of from engineering fidelity (for example, false target cues for sonar classification); and for Level 5, the decision deals with special features of the training system and concerns the desirability of deliberately deviating from the engineering fidelity continuum to enhance transfer effects (for example, employing a stimulus enhancement technique on a primary visual display, or displaying alpha-numeric performance information (augmented feedback) directly on a student's CRT display).

The whole array of the simulation elements that must be evaluated for representation in the design of the trainee station(s) to achieve control, display and procedural requirements, is presented next. These elements of simulation are organized in terms of own-ship and support units, target, and media characteristics. For each class of task element within each of these three groupings, decisions must be made about various dimensions of fidelity required. To aid in this determination, the five levels for evaluating fidelity of simulation, identified in Table 39, are used. Thus, in the following outline, the relevant classes of simulation elements are grouped within major subsystems applicable to the device under consideration.

TABLE 39. FIDELITY OF SIMULATION LEVELS FOR EVALUATING SIMULATION ELEMENTS

Level	Description
1	Inclusion/exclusion of the element.
2	Representative envelope/steps/value for the element.
3	Degree of fidelity required (where engineering state-of-the-art is adequate).
4	Fidelity achievable where reduction in tolerances is required (where engineering state-of-the-art is less than adequate).
5	Deliberate departures from realism to enhance training effectiveness (deviations in configuration/operation associated with the operational system being simulated).

This is accomplished (as applicable) independently for each of the simulation areas (own-ship, target, media) since the classes of simulation elements are different for each area. Thus, for example, the classes of simulation elements for the sonar subsystem are identified for own-ship and support units, again for target characteristics, and again for the simulated medium. The appropriate fidelity dimension(s) to consider is indicated (identified by corresponding number in Table 39) for each class of simulation element in each subsystem for each of the three simulation areas.

4.5.1.2.2 Simulation Elements to Represent in Device 14A2

I. OWN VEHICLE AND SUPPORT UNITS

A. SONAR (Electronic Visual Symbol Display)

1. OWN-VEHICLE RETURNS (fidelity dimensions ①③)

• own-ship noise (flow noise, turbine noise) • wake	appropriate video/audio characteristics; appropriate video degradation as a function of speed of increase correlated

• knuckles • torpedo hydrophone effects • countermeasures	with optimum sonar speed; appropriate audio degradation as a function of speed increase correlated with optimum sonar speed.

Note: Neither own-ship wakes or knuckles are presently provided in 14A2. Thus, no opportunity is provided CIC to plot or otherwise account for the phenomena and to coordinate with sonar to prevent acquisition and tracking of these false targets.

Note: Audio degradation is presently provided but is not effective below 22 knots. Screw beats are heard above 22 knots and contact can unrealistically still be held when own-ship speed is at 34 knots.

• cavitation	own-ship cavitation sounds should be detectable when cursor is placed in baffles area; no video

2. SUPPORT UNIT RETURNS (fidelity dimensions ①③)

• support ship(s) (aspect) • echo-ranging effects (mutual interference effects from surface ships, dipping helos, sonobuoy) • knuckles • wakes	video: appropriate blip size, shape, brightness for the vehicle, correlated with aspect audio: appropriate echo quality, doppler effects correlated with aspect

Note: In the present 14A2 device configuration, sonar returns are not sensitive to vehicle size or aspect which are cues to classification (classification is discussed in Paragraph 4.5.1.2.3.1) as to the effects of echo ranging, mutual interference effects are not presently simulated. These effects would have training value for screen and SAU operations. Neither knuckles or wakes from friendly forces are simulated--again these are good sources of false targets.

3. PPI DISPLAY CHARACTERISTICS (fidelity dimension ③)
    - echo quality
    - pip quality (aspect)
    - axis angle
    - trace length
    - differential range rate
4. VISUAL DISPLAY REQUIREMENTS (fidelity dimension ③)
    - acuity
    - luminance
    - refresh rate (flicker)
    - contrast sensitivity
    - resolution
5. TRANSFER OF SONAR DATA TO FIRE CONTROL SUBSYSTEM (fidelity dimension ③)
    - range, speed, bearing, target course (manual insert)
    - generated target tracking

B. RADAR (Electronic Visual Symbol Display)

1. OWN-VEHICLE RETURNS (fidelity dimensions ①③)
    - reflection echoes
    - wake
    - superstructure masking (dead zones)
    - interference from other radars in own vehicle or in proximity to own vehicle
    - antenna height above water

Occurrence is associated with vehicle type. Appearance and definition are correlated with envelopes of occurrence for vehicle type and speed.

> Note: Own-ship returns are not provided for in the 14A2. This is a design option that would yield sources of false contacts.

2. SUPPORT UNIT RETURNS (fidelity dimensions ①,③)

- surface ships
- aircraft (HS, VP, VS, DASH)

blips for ship and aircraft should be proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected

> Note: Ship and aircraft returns are presently provided in the device, however, blip size is not proportional to vehicle size or aspect. Maximum range is not realistic (limited radar horizon).

- wakes

appearance and definition should be correlated with ship actual speeds

> Note: The design option to provide wakes on the radar display was not selected.

3. PPI DISPLAY CHARACTERISTICS (fidelity dimensions ①③)

- range strobe
- sweep line
- offset features
- target designation feature

4. SELF TEST INDICATIONS (fidelity dimensions ①,②)

5. VISUAL DISPLAY REQUIREMENTS (fidelity dimension ③)

- acuity
- luminance

- refresh rate
- contrast sensitivity
- resolution

6. DISPLAY REQUIREMENTS FOR VECTORED ATTACKS (fidelity dimensions ①②)

Symbology is required for WSA-1 (symbol generator) to show: water entry point for aircraft launched torpedo; contact range and bearing; and position of DASH vehicle.

Note: Current WSA-1 symbology in the 14A2 utilizes the following designs. These are adequate.

+	indicates water entry point as determined by weapon motion analysis in UB/Plot
⊡	Indicates sonar contact range and bearing
H	Indicates range and bearing input from fire control radar (DASH position)

Note: The radar in the 14A2 has no sweep line and there is no offset feature. Surface ships are presented as blips that are not proportional to the length, aspect angle and range of the ship. Surfaced submarine blips are also consistent in size regardless of aspect and the intensity of presentation. Periscope depth submarines have fixed length blips with an intensity based on sea state; to increase realism, presentation of the blip is interrupted at random. Aircraft have fixed length, fixed intensity blips within a representative maximum detection range. No sea return is provided on the radar display. It appears that high fidelity representation was not selected due to the prohibitive costs (e.g., sweep servo generator) when compared to the additional training value achieved.

C. VEHICLE DYNAMICS

1. VEHICLE CHARACTERISTICS (fidelity dimensions ①②⑤)

Own-Ship - Based on the types of surface ships that will send teams to the 14A2 device; own-ship dynamics should be a composite of FRAM I conversions, 1040/1052 DE, DEG, DLG, and CLG.

Note: Present vehicle dynamics in the 14A2 are a composite of a DD type (Gearing Class) and a CLG.

Support Destroyers - Two assist ships are required to provide the training capability defined for SAU operations in the training objectives. The vehicular dynamics are those available for own-ship.

Note: The 14A2 employs the composite dynamics as defined for own-ship.

Aircraft - Three aircraft are required to provide the VECTAC operations as defined in the training objectives for SAU missions. The characteristics should represent VS, VP and HS dynamics in any combination of the three, or when DASH operations are involved, any two aircraft combinations plus one DASH are employed. DASH Characteristics are those of the actual vehicle.

Aircraft Carrier - CVS/CVA Vehicle Characteristics are desired to provide more realistic radar and sonar returns. Also carriers are employed in screening operations (i.e., ASW in the vicinity of the screen).

Note: The second target submarine in the 14A2 (sub 2) is used to represent the carrier. Since vehicle size differentiation is not portrayed in the device, the use of the second sub for the carrier is not a drawback for training as currently accomplished.

The vehicle dynamics appropriate to the types specified above should be programed to include:

Speed range
Acceleration/deceleration characteristics
Ordered course
Turn rate
Turning radius
Dive/climb rate
Ordered depth/altitude
Response lag

The programed vehicular dynamics should result in the appropriate relative motion of vehicles displayed in sonar, radar, NC-2/DRT and appropriate program envelopes of speed, sea state, and water depth should result in the generation of non-submarine contacts on sonar (ex., surface ship wakes and knuckles), radar (wakes), and also, submarine contacts such as hydrophone effects, wakes and knuckles.

Note: These characteristics are not provided in Device 14A2.

Own-ship dynamics should also be represented in the functioning of ship control instruments (e.g., gyro-compass, pit log, rudder angle indicator, and Mk 78 position indicator).

D. WEAPONS SUBSYSTEMS

1. OWN-SHIP (fidelity dimensions ①②)

ASROC Battery - Capable of adjustment in train and elevation angle

ASROC Missile - Trajectory program to cover present firing range capabilities

Mk("X") Nuclear Depth Charge

Mk 25 AWTT - Fixed train angle

Mk32 AWTT - Trainable

Note: The Mk 32 is not trainable in the 14A2; it is fixed at 45°.

ASW Torpedoes- Current torpedo dynamics for Mk 44/1 and Mk 46/0 should be simulated for ASROC, AWTT, and DASH delivery, to include run out patterns and homing features.

2. SUPPORT UNITS

VS, VP, HS and Surface Support Units - Capable of firing the above ASW torpedoes.

Note: In 14A2, only the support aircraft can release weapons. An additional training objective could be achieved in coordinated SAU attack if support units had a weapon firing capability. Also, friendly unit hydrophone affects are desired but not available.

3. TARGET SUBMARINES

Torpedoes - Capable of firing torpedoes against own-ship or surface support units.

Note: 14A2 submarine can fire only one torpedo and only on own-ship. No display of weapons actions (e.g., water splash point of air to water missile) is provided. Tactical training capability can be extended by enabling the submarine to fire salvos of three torpedoes.

4. MATERIAL COUNTERMEASURES

Fanfare - Towed noisemaker should be simulated in terms of streaming and activation. It should be programed for own-ship and available for other surface support units.

Note: In the 14A2, Fanfare is available only for own-ship. If available for other surface units, it would provide another source of degradation for the Sonar display.

E. MALFUNCTION CAPABILITIES (fidelity dimensions ①②)

A design option for the device involves incorporating types of malfunctions as a means of exposing teams to various real-world contingencies and as a means for increasing the difficulty within groups of training exercises.

Note: 14A2 design provides a malfunction capability only for weapons in terms of launch functions. Weapon selection on the Attack Director Firing panel can indicate failure in cells, train and elevation angle, or indicate a dud. No other classes of malfunction are available.

Additional malfunction capabilities important to satisfying the training objectives could include the following:

Sonar - audio, video failures

- Complete failure would force own-ship to execute a Deep Creep attack (own-ship Vectored in to attack).

NC-2 Plotter - Compass rose failure would force the utilization of the Halifax plotting method.

- Green/red bug failure would force the use of manual plotting procedures.

Radar - Degrading of resolution (e.g., range, video).

- Intermittent failure would force the use of ASAC dead reckoning procedures.

Attack Director (attack plotter section) - Cursor or flasher light failure would force a fire control solution via CIC.

Weapons - Propulsion failure would force the team to initiate quick reattack procedures.

RT Nets and MC Circuits - Communications failures would force a redesignation of RT Nets and the use of the MC system.

F. FIRE CONTROL DISPLAY REQUIREMENTS (fidelity dimensions ①②)

- sensor data handover (target range and bearing information)
- range and bearing indication of target (target position) (flasher light)
- own vehicle display symbol (on geographic display)
- cursor dynamics and control (cursor display for solution of target course; crank control; speed shadow control for solution of target speed)

- status information
  - channel assignments and loading
  - weapon status
  - rail status (up/down, loaded/empty)

G. DELIBERATE DEPARTURES FROM REALISM

This deals with special features of the 14A2 device where deliberate deviations in design from the operational equipments, other than the engineering fidelity continuum, are installed to enhance training. Prime examples of this are the use of target enhancement techniques on trainee displays, or providing immediate knowledge of the results of performance directly on a display in a trainee compartment.

No real use is made of this design option in device 14A2 with the exception of the Bridge compartment and Radar. The helm employs rotary controlled potentiometers for setting own-ship course and speed instead of actual ship controls; the functional capability and the PPI display of the radar are different from that found aboard ship. The radar, however, may be described as lacking in engineering fidelity more so than as a deliberate departure in design from operational realism.

II. TARGET

A. SONAR

1. TARGET CHARACTERISTICS (fidelity dimensions ①②)

- Number of targets to represent at a given time in the mission environment (one submarine is displayed in the 14A2).
- Classes of targets. Both nuclear and conventional submarine vehicle dynamics are required, equivalent of Russian "November" and "Foxtrot" vehicles.

Note: The device employs the dynamics of the Nautilus class (nuclear) and the Guppy II class (conventional). Two target submarines are programed in the device although only one submarine is usually represented in any engagement.

Note: Accelerations and decelerations for nuclear submarines are not realistic in the 14A2. For example, to decelerate, one must freeze the movement and knock down in 5-knot units to achieve the desired speed.

- Target appearance /disappearance/attenuation as a function of range and sea conditions. The detection range available should correspond to the full range achieved operationally.

Note: A serious limitation in present design of 14A2 is that the maximum detection ranges available are not achieved in the device. An empirical study by Dunlap and Associates, Inc., utilizing device 14A2A indicated detection ranges under 10,000 yards. For example, a detection range of only 9,000 yards was achieved on the device for these conditions: sea state 1, 100 foot layer, submarine depth of 50 feet with a beam aspect. This shortened detection range, hampers the training capability in that it prevents extended utilization of standoff weapons systems. Full training potential with VECTACS and DASH are not exercised since the greatest difficulty in control occurs at the greater distances resulting from greater range and bearing errors.

- Target movement as a function of range, bearing and aspect changes.

2. TARGET VEHICLE RETURNS (fidelity dimensions ①③)

• aspect (bow, beam, stern)	video - appropriate blip size, shape and brightness persistence for brightness modes audio - doppler effects (up, down, no) via increase/no increase/decrease in pitch over transmission frequency

Note: There is no video correlate for aspect in the 14A2.

• cavitation effects • hydrophone effects from torpedo	video - appropriate noise spoke for speed, depth, range and BT envelopes audio - appropriate audio characteristics for speed, depth, range and BT envelopes
• knuckles • wakes	video - appropriate blip size, shape, and brightness persistence for brightness modes

audio - appropriate audio characteristics

Note: The design option for providing false targets is not employed in the 14A2. Also, submarine wakes are not presently provided. With a display of wakes the situation exists for the sonar operator to erroneously "track off" on wake trails. It also provides an evasive capability for the submarine for exercises emphasizing tactical deception and greater own-ship threat evaluation.

B. RADAR

1. TARGET CHARACTERISTICS (fidelity dimensions ①②)

- Total number of targets to represent in mission environment
- Classes of targets
- Number of targets displayed simultaneously/instantaneously (number that the trainee is capable of processing in his span of control)
- Target appearance/disappearance/attenuation as a function of range/altitude and environmental conditions (e.g., radar fades, height of antenna)
- Detection ranges should correspond to full range achieved operationally
- Capability for add-on of new targets (for updating)

2. TARGET RETURNS (fidelity dimensions ①③)

- submarine

- surfaced	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected
- periscope depth/ snorkel	

Note: Both of these factors are provided in the device, but the intermittency prog.am affects the periscope returns. Blip size and shape for surfaced submarine is not available.

- feathers	appearance and intensity correlated with submarine speed at periscope depth

Note: The display of feathers is not provided for in device 14A2.

- aircraft

- speed and maneuvers	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected
- relative motion	
- lock-on indications	
- target identification (e.g., SIF)	

- surface vehicle

- speed and maneuvers	blip proportional in size, shape and brightness to vehicle type, aspect, range and range scale selected

3. TARGET DISTORTIONS (fidelity dimensions ①②)

- garbling (signal overlap)

III. MEDIA

A. SONAR

1. ENVIRONMENT (fidelity dimensions ①②)

- Wind direction and speed

  0° - 360°/0-100 knots

The design requirement is the capability of wind direction and speed to affect all air operations and to affect sea state.

Note: 14A2 design employs wind direction and speed to affect only DASH and ASROC (automatically). Aircraft operations are not affected by wind forces.

- Sea state

Sea state range of 1 to 6, correlated with wind speed to cause degradation on sonar (reverberations) and on radar (sea returns).

Note: 14A2 design does not correlate sea state with wind speed. Sea states of 1 to 6 are achieved with a reverberation control for sonar.

- Bottom depth/type

The desired option is to provide a controllable depth from 100 feet to 2000 feet and showing characteristics of rocky and sandy bottoms for a realistic sonar environment. This will also permit training in shallow water operations.

Note: 14A2 design does not have controllable bottom depth. A 2000 foot bottom is assumed in the program. The option not to depict bottom characteristics is presumably based on the decision to omit the training objective of shallow water operations.

- Thermal gradient

Representative sampling of the layer depths, operationally experienced, are required.

Present design employs the following increments:

0, 50, 100, 200, 300 and isothermal.

- Land masses

A desirable design option is to provide sonar and radar depictions of two representative harbor areas for team training in shallow water operations. This is not simulated in the 14A2 presumably based on the decision to omit the training objective of shallow water operations.

- Ocean area

X-Y coordinate system (flat plane of reference) encompassing a maximum of 64,000 x 64,000 yards area is sufficient to provide the tactical environment specified by the training objectives.

- Altitude

A 'Z' coordinate representative of sea level to 5,000 feet for fixed-wing aircraft and sea level to 3,000 feet for helicopters is sufficient for air operations.

2. RANGE (fidelity dimension ②)

- envelop of detection ranges that are achieved operationally (appearance/attenuation of targets)

3. NON TARGET RETURNS (fidelity dimensions ①③④)

a) Non-Submarine Returns - Natural

• Reverberations	Appropriate video and audio characteristics

Note: Reverberation simulation is not satisfactory in the 14A2; it is presented via a random generator, with a control labeled "SEA STATE" (1 through 6). The sea state is not correlated with wind speed. Thus, unrealistic events may be achieved (e.g., sea state 1, windspeed 22 knots).

• Bottom returns (sandy, rocky)	Video characteristics for typical "soft" and "hard" bottom configurations Appropriate audio characteristics

Note: Absence of bottom return in the 14A2 limits training in shallow water exercises.

• Fish, whales, reefs, wrecks and pinnacles	Appropriate blip size, shape and brightness for brightness modes Appropriate doppler effects, echo quality

Note: False target options are not provided in 14A2 simulation. This obviates the necessity for the use of bottom charts and CIC keeping track of underwater obstructions.

b) Non-Submarine Returns - Submarine Launched

• Torpedo hydrophone effects	Appropriate audio characteristics Appropriate noise spoke
• False target cannisters, decoys, jammers (NEA beacon)	Appropriate video characteristics Appropriate audio characteristics

Note: False targets not provided for in device design (see above). Submarine tactical countermeasures are not employed.

c) Non-Submarine Returns - Own-ship Launched

• Torpedo hydrophone effects	Appropriate video characteristics Appropriate audio characteristics
• Fanfare	

Note: No torpedo hydrophone effects are displayed on Sonar resulting from own-ship fired torpedoes. Fanfare is not displayed on Sonar.

4. BACKGROUND CLUTTER/NOISE ON DISPLAY (fidelity dimensions ① ③)

Summary: Sonar Video Simulation

The Sonar video simulation is cleaner in what is portrayed than in the operational environment and it is also less flexible. There is a limited capability for deliberately degrading equipment performance. The Sonar operator is denied the classification task since most of the parameters associated with uncertainty in target identification are not represented in the device. With the classification function present, more effective use of the device could be made in a program of training where additional training value would accrue in complex multi-unit exercises involving tactical employment of own-ship (i.e., fighting the ship).

B. RADAR

1. ENVIRONMENT (fidelity dimensions ① ②)

- wind direction/speed

- sea state
- altitude
- land mass/elevations

2. RANGE (fidelity dimension ②)

- envelop of detection ranges achieved operationally (appearance/attenuation of targets)

3. NON-SUBMARINE RETURNS

• second sweep echoes • radar decoys	blip characteristics should be similar to operational characteristics

Note: These are not available in the device. This design option would provide sources of false contact information.

• sea return	density and brightness should be correlated with sea state and range

Note: Sea return is not available in the device. This design option would increase the difficulty in radar detection.

- land mass characteristics

Note: Land masses are not displayed. This design option would increase the fidelity of training in shallow water operations.

4. BACKGROUND CLUTTER/NOISE ON DISPLAY (fidelity dimensions ①③)

5. INTERFERENCE EFFECTS FROM MULTI-SHIP ENVIRONMENTS (fidelity dimensions ①③)

4.5.1.2.3 Simulation Elements Summary. The simulation elements involved in installing the tactical environment for training must be pertinent to, and of sufficient number and range of values to provide the means for accomplishing the classes of training exercises described earlier. The total array of the simulation elements presently organized in the device, provides for effective ASW team training. That is to say, with the device configuration as a given, effectively developed utilization procedures (e.g., a graduated series of training exercises such as indicated in the section on training objectives) can accomplish training from Fire Control Solution and Launch Procedures in a one-on-one situation through a range of SAU exercises (the SAU context places the greatest design requirements on the device). For example, a number of complex SAU missions can be accomplished in Device 14A2. Figure 51 shows the SAU missions that can be accommodated. An "X" denotes a primary training mode; a "B" denotes a secondary or backup mode; a "P" denotes a possible training mode. Blank cells denote either non-relevancy or no training possibility.

However, a number of the design options indicated earlier and not selected for the 14A2 have effects on training. Some are easily defined, others are not, but all are of importance in human factors design. Some examples of these effects are shown below.

4.5.1.2.3.1 Signal Characteristics--the design goal is to provide target signals which are realistic of the range of real-world events. The 14A2 is not a large multi-signal environment, most often, only a single submarine signal is displayed plus a maximum of three aircraft and two assist ships and the possible use of the second submarine (SU-2) as a vehicle. The characteristics of the target must be well defined. For the most part, Sonar simulation is adequate, yet complete fidelity is not achieved, for example, provision of classification cues. The effect of this is to introduce a lack of realism in exercise structure. There is less than desired involvement of the Sonar and the CIC subteams in tactical decision making sequences. Certain training objectives are not achievable and there are certain losses in controlling the exercise difficulty. Yet the effects of this on transfer of training are not clear except on logical grounds which point clearly to the desirability or training with the classification task in ASW. But if teams are exposed minimally to training (such as a recurring schedule of two days of training in a three-month period), the cost factor outweighs the training benefit, since much of the team efforts are devoted simply to refining their team procedural skills. Usually, teams that return to the trainer in a six-month period show better than a 50 percent turnover in personnel.

4.5.1.2.3.2 Absence of Simulation Elements. A number of the design options that would enhance the training capability but are not reflected in present 14A2 design (Sonar and Radar Display limitations, absence of

No. of Units			RED PLANS												BLACK PLANS												
			ATTACK								SUPPORT				SEARCH												
			← Deliberate →					← Urgent →																			
DD	VS	HS	Lock-on (1A)	Deep Creep (2A)	Geo. Sector (3A)	Squeeze (4AH)	VECTAC	ASROC (IFR)	DASH (IFR)	AWTT	MADVEC	Bear (11A/AH)	Fence (13A/AH)	Redwood (12A)	Acorn (2S)	(2SH)	Oaktree (1S) Area	Intercept	Lost Contact	Bottom	Oaktree (1SH) Area	Intercept	Lost Contact	Bottom	Pineapple (3S)	(3SH)	MAD Trapping
1								X	X	X															P		
2			X	X	X			X	X	X					X		X	X	X	X					X		
1	1						X	X	X	X	X			Requires 3 or more ships											P		X
1	2						X	B	B	B	X														P		X
2	1		X	X	X		X	X	X	X	X				X		X	X	X	X					X		X
2	2		X	X	X		X	B	B	B	X				X		X	X	X	X					X		X
1		1				X	X	X	X	X			X													X	
1		2				X	X	B	B	B			X													X	
2		1	X	X	X		X	X	X	X			X			X					X	X	X	X		X	
2		2	X	X	X		X	B	B	B		X	X			X					X	X	X	X		X	
2		3	X	P	X		X	P	P	P		X	X			X					X	X	X	X		X	
1	1	1				X	X	B	B	B	X		X													X	X
2	1	1	X	X	X		X	B	B	B	X		X			X					X	X	X	X		X	X
2	1	2	X	P	X		X	P	P	P	X	X	X			X					X	X	X	X		X	X
2	2	1	X	P	X		X	P	P	P	X		X			X					X	X	X	X		X	X

X = Primary Mode
B = Backup Mode
P = Possible but unlikely mode

Figure 51. SAU Exercises That Can Be Accomplished In The Present Device 14A2.

certain environmental features, malfunction capabilities), serve to increase training value in that they encourage greater involvement in task performance, increase problem difficulty levels and confound tactical solutions thereby heightening the tactical decision-making requirements. Yet, a program has not been undertaken to obtain evidence that these will produce a greater transfer of training to the real-world. At best, it can only be logically or intuitively stated based on the research literature, that training will be enhanced. Although training value is unknown, it is clear that greater training flexibility is achieved and this in itself is desirable. What must be done is to weigh these logical gains against training purpose and make the necessary cost tradeoffs (which at present is a highly imprecise art).

So far as the unresolvable areas of design are of concern, the question is, how far can we back off from 100% fidelity and still achieve our training purpose? Since training value data are lacking, the question of "nice to have" vs. "needed" in simulation is inexactly resolved. Quite often, as history has shown, solutions are based on "unusual" criteria. Related to this is the question of how far must we go in design to get the desired performance? Again, the question is tied in with training purpose and the objectives of training, but cost is an overriding feature. Unfortunately, more research issues than facts have been generated by these crucial questions.

4.5.1.3 Output. Identification is made of the crucial factors in representing the operational environment in the trainee compartments. The functional characteristics of trainee compartment design consider most prominently the issues involved in achieving simulation fidelity in creating an environment for learning. The completion of this phase yields the following:

- Configuration of the synthetic system (in terms of the extent of representation, the hardware components in the trainee compartments and specific equipment requirements.
- Definition of operational task structure.
- Definition of the simulation elements (parameters to be simulated which govern the range and complexity of task representation in the device and which are required to achieve training purpose and the training objectives).
- Special features in trainee station design which presumably will enhance training value in terms of greater transfer of training to the operational system.

4.6 THE MANAGEMENT OF TRAINING--STRUCTURING, CONTROLLING AND MONITORING TRAINING AT THE INSTRUCTOR STATION. In addition to the design issues involved in installing the environment in which learning can take place (simulation of the trainee compartments), there are design issues associated with the structuring, control and monitoring of training. This involves the management of training at the instructor station, i.e., how the device will be utilized as a training tool.

The human factors design of the instructor station complex emphasizes the idea of design for training utilization. Given the environment for learning (trainee compartment design), the concern is for how the synthetic environment will be used for training and for creating and monitoring training situations in order to shape team behaviors and to optimize the training strategies for teams during the course of instruction. The design requirement is to provide a capability for structuring training so that the important mission and system events can be installed and controls provided to insure that these events occur in prescribed ways at prescribed times. This calls for a flexibility in training capability so that the defined situations can occur at the desired times in order to satisfy the training objectives.

A human factors design pathway is developed to provide an instructional capability consistent with the training purpose and the design of the trainee compartments. The approach consists of evaluating the information requirements for the instructor station and examining the design alternatives and selecting those design options most relevant to achieving the desired training. Defining the design pathway involves evaluation within the following areas:

a. The training device mode of operation
b. Analysis of instructor functions
c. Instructor requirements
d. Display requirements
e. Control requirements
f. Monitoring and control of training (enroute during the exercise)
g. Pre-mission requirements
h. Post-mission requirements
i. Measurement system requirements
j. Communications requirements
k. Overall layout and workplace requirements

4.6.1 Mode of Operating the 14A2 Device

The initial consideration involves specifying the operating modes at the instructor console in controlling, monitoring and evaluating team training. These modes range from manual operation to semi-automated and automated operation. The selection of operating mode must be considered carefully because of the hardware and computer programing requirements.

> Note: The decision was made to operate the instructor station in the manual mode. Our analysis will examine the requirements for achieving this capability (a discussion of instructor station modes is provided in Paragraph 2.8.1 of Section II of this report).

Decisions must be made about instructor involvement in the total training mission sequence beginning with pre-exercise briefing and the setting up of initial conditions for an exercise, the control of mission events via a script of event setups during the actual running of the mission scenario, and ending in post-exercise critique.

4.6.2 Analysis of Instructor Functions

An identification and analysis of instructor functions in the manual mode is undertaken for the activities involved in pre-mission setup, enroute mission operations and post-mission activities. The display control and communications requirements are specified for the following classes of operations and instructional functions.

- initialize system for mission operation
    - checkout of subsystems
    - power
    - projection display equipment (Universal Program Generator)
- setup of initial conditions
- student briefing (including demonstration mode where applicable)
- monitor and control of team performance (hardware provisions for the following):
    - exercise start (COMEX)
    - exercise freeze
    - override of scenario (as applicable)
    - demonstration mode
    - control of events throughout mission (time and event control of problem manipulatibles via graduated series of training exercises in the utilization guide)
    - problem speed control (fast time (2X) to reduce runout time required when a team makes a wrong weapon assignment)

  - communications with trainees, and remote instructors
  - instructional assists for unburdening the instructor (e.g., hit assessment light (computer function)
- evaluation and scoring requirements
- mission termination
- post-mission critique
  - equipments for critique (projection display equipment, audio recording)

The display, control and communications requirements for the identified instructor functions can now be analyzed in the detail necessary to achieve the desired design pathway for the instructor station. Table 40 presents the instructor functions analysis.

4.6.3 Instructional Staff

Based on workload estimates, instructor manning requirements range from three to eight according to type of training exercise being conducted. Early in the training sequence, a minimum of three instructors appear to be needed in certain exercises to achieve the balance between control of the exercise and assisting/observing team performance in the compartments. For example, an ASROC RTDC attack exercise requires:

One instructor at the master console to conduct the setup of initial conditions, control the target submarine and monitor the 1JS.

One instructor in the CIC compartment to observe and assist performance and complete a team performance checklist (assessment).

One instructor in the UB/Plot, Sonar compartment to observe and assist performance and complete a team performance checklist (assessment).

An example of a more complex exercise, and one that imposes the greatest instructor manning requirements is an AWTT 44-1 torpedo attack from a sector screen. The instructor requirements here are as follows:

TABLE 40. ANALYSIS OF INSTRUCTOR FUNCTIONS FOR DEVICE 14A2

Function	Display Requirements	Control Requirements	Equipment
System initialization	Proper ASROC launcher position	Program insertion	114 Fire Control System
	System data cleared (all zeros)	Insert parameters of the vehicle	Computer tape
	Project in system	Initiate & align the projection system including new slides	
	Time clock at time zero		
	Power-on indication	Power-on controls	(Note: the above are functions performed by the training device operator (TD))
Exercise set-up (initial conditions)	Unit types (own-ship, support units, submarine target)	Vehicle program designator	Master control console keyboard
	- x,y positions - depth/altitude of vehicles - own-ship initial course and speed	For specific vehicle, controls to enter these data	
	Weapon selection/loadout		
	Delivery system		
	Environmental conditions - sea state - layer depth - wind direction/speed		Environment console

TABLE 40. ANALYSIS OF INSTRUCTOR FUNCTIONS FOR DEVICE 14A2 (Continued)

Function	Display Requirements	Control Requirements	Equipment
	Sea area (64 x 64 miles, 32 x 32 miles)	Controls to enter these data	Master console, projection system
	Communications circuits selected	Controls for positioning selected circuits	
	Weapons load	Controls for installing full weapon load	
	Universal Program Generator setup	Controls for setup of Universal Program Generator (for tape replay)	
Team briefing			Projection equipment
Enroute mission operations (inputs as required)	Own-ship position Contact (range & bearing for submarine position required for contact insertion converted from x, y, z coordinates) Fire control solution readouts Friendly weapon readout (water entry point)	Enabling controls	Required: Master control console Vehicle control console Display control console Fire control console Seascape PPI console Vehicle data console Sonar and PPI console

TABLE 40. ANALYSIS OF INSTRUCTOR FUNCTIONS FOR DEVICE 14A2 (Continued)

Function	Display Requirements	Control Requirements	Equipment
	Weapon presetting information (ISD, floor)		
	Sonar operating status and PPI		
	Time readout from contact to attack (firing interval)		Timer
	Submarine maneuvering	Keyboard commands for maneuvering	
	Maneuvering/ control of support units (surface aircraft guidelines from ASAC if under positive control; if advisory control, as briefed)		
	Weapons selection and weapon active indication		
	Hit assessment	Control to clear hit light	
	Submarine torpedo launching (hydrophone effects)	Control sequence	
	Support unit torpedo firing (aircraft)		

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TABLE 40. ANALYSIS OF INSTRUCTOR FUNCTIONS FOR DEVICE 14A2 (Continued)

Function	Display Requirements	Control Requirements	Equipment
----	Malfunctions Event symbol display on trace Decoy insertion		Projection system
Modify environment parameters	Appropriate displays	Appropriate controls; problem start-stop capability	
Own-ship control	(for demonstration	purposes)	
Control of communications inputs (inter-ship)	Aircraft reports via ASW air control net, SAU commander directs surface support units via SAUTAC, CI nets, directives from OTC via PRITAC, directives from screen commander via ASW screen common	Appropriate controls	Light displays on console
Communications monitoring	Access to RT nets, sound powered phones and MC nets, monitor desired circuits on tape (1JS)	Audio receiving controls	Audio receivers, audio tape recorder
Feedback of performance information to team (guidance during training)	Indications of team performance (see above)	Communication controls	

TABLE 40. ANALYSIS OF INSTRUCTOR FUNCTIONS FOR DEVICE 14A2 (Continued)

Function	Display Requirements	Control Requirements	Equipment
Performance assessment	Objective scores (time, accuracy) of team outputs, communications		Time & accuracy readouts
Strategy for sequencing training	Indications of team performance (see above)	Enroute modification of exercise parameters (see above)	
Exercise completion	Indication of exercise completion	Controls to shut down the system when required	
Post-exercise critique (exercise reconstruction and assessment)	Measurement information; panoramic depiction of tracks of all vehicles	Exercise playback capability in real time, 2X, 4X and 8X real time	Universal program generator (replay)

One instructor at the master console to conduct the setup of initial conditions, and control the target submarine.

One instructor at the master console to control destroyer 1 (SU1), perform the functions of screen commander and issue/monitor communications over the screen common net.

One instructor at the master console to control destroyer 2 (SU2) and monitor communications over the CI net.

One instructor at the master console to control a support vehicle (an oiler), perform functions of the OTC and monitor the PRITAC net.

One instructor in CIC to monitor/assist performance and complete the CIC team performance checklist (assessment).

One instructor in UB/Plot and Sonar to monitor/assist performance and complete the team performance checklists for UB and Sonar (assessment).

One instructor on the Bridge to monitor/assist performance and complete the team performance checklist (assessment).

One instructor having overall cognizance of the training exercise and monitor the 1JS circuit.

In cases requiring the maximum number of instructors, doubling up of functions may be necessary. Where possible the staff should attempt to double up on vehicle control functions so that the trainee compartments may be covered by instructors.

4.6.4 Display Requirements

A key requirement in instructor station design is the efficient display of team performance information. The specification of display requirements is largely dependent on the information requirements in terms of information content; amount, variety, and speed of information change; and complexity. The information classes to be displayed account for the following:

- Mission areas--the mission/tactical environment/relative geometry in the pertinent display modes (32 x 32, 64 x 64, 128 x 128, 256 x 256 mile areas).

- target data
    - target contact--(onset/attentuation/disappearance of targets as a function of range and other pertinent factors)
    - tracks
    - range/bearing information, doppler, aspect, depth/altitude
- Own-ship and support units
    - identity, position and tracks, movements
- Indication of the system state/simulator mode of operation and the present phase or point in the mission
- Status of events (e.g., event symbol visual display)
- Performance information on each team (error indications)
- Indication of the team control/tactical actions and/or consequences of team actions, for monitor and control of training (e.g., range scale settings, sector selection, selection of operating modes such as MAD, deployment of sonobuoys)
- Indication of team detection/identification of targets once displayed (event and time of event). Note: an indicator light is used in the 14A2 to show that a contact is made.
- Indication of instructor actions once initiated/controlled over time
- Information for manual control functions (e.g., position, heading, altitude/depth and speed information for "flying" an aircraft or controlling a submarine target)

4.6.4.1 Display Techniques. Decisions on primary display techniques (media and mechanization) for monitor, control and evaluation of training are based on a correlation of the information requirements for the system and the characteristics of classes of display.

- Repeater displays (reproductions of trainee displays)

- Event on/off indications (e.g., indicators depicting an out-of-tolerance event, a trainee mode selection, or instructor insertion of an event (control/display integration) such as a malfunction)
- plotting boards (mechanized)
- Computer generated displays--synthesized multi-format/integrated displays (e.g., Cathode Ray Tube display of alpha-numeric/pictorial-situational information)

Note: All of the above techniques are used in the 14A2 except computer-generated displays (CRTs).

4.6.4.1.1 Criteria for Defining Primary Display Requirements. Decisions on primary display techniques and display modes/format requirements should consider the following criteria.

- Information handling capability (amount, types, rapidity of change, number of trainees under control)
- Multi-format requirements, high density information display, information integration (alpha-numeric and situational/graphic display requirements involving discrete event and overall situation displays; continuous alpha-numeric error readouts)
- Rapid mode changes for monitoring, control and evaluation, requirements for monitor and control of more than one subteam sequentially
- Display flexibility (with relevant controls)
    - mission/geographic areas
    - scale depictions
    - information classes
    - display modes
    - coding of displayed information
- Accuracy, reliability and registration (information alignment) of the visual displays
- Expansion capability (for future display requirements)
- Visual factors

- acuity
- luminance
- refresh rate/flicker
- contrast sensitivity
- resolution
- clutter

4.6.4.2 Ancillary Display Requirements. Requirements are also specified for those displays not primarily involved in the instructional process but which are necessary to training system operation (e.g., mission timers, system status displays, etc.)

4.6.5 Instructor Console Controls

4.6.5.1 Control Requirements in the Mission Sequence. To achieve full use of the instructional capability, a number of classes of controls are required to operate the training device and to enable the shaping of behavior in the trainee compartments. The control classes include the following:

- Device operation--start, freeze, reset, override.
- Means for selecting displays and display modes (multi-format displays).
- Means for controlling vehicles (e.g., controls for "flying" an aircraft, steering a target submarine).
- Means for positioning units in the mission, both initially at problem start and during the mission.
- Means for direct access to the device computation system (manual input controls (keyboard).
- Environmental controls.
- Communications controls.
- Means for simulating failures/emergencies.
- Means for inserting mission events during an exercise
- Means for eliminating defined programmed events (for example, elimination of slug, sonar contact, radar contact)

4.6.5.2 Selection of Controls. Decisions on the selection of controls for operating the instructor station and controlling the training are based on the following criteria:

- Display-control compatibility (compatibility with tabular and graphic formats).
- The amount and types of information and speed requirements in information reception and transmission.
- Number and size required to avoid clutter, ambiguity and needless redundancy because of the potential for error in usage.
- Ease of operation, particularly where instructor to trainee ratios are high.
- Efficiency of panel space usage.

Instructor console controls can be grouped according to the functions performed (obtained from instructor functions analysis) which in turn affects the choices in control selection.

4.6.5.2.1 Mission/Instructional Controls--(on-line). These are the major groups of controls used for structuring and controlling training during the exercise, and range from switches through control-display indicators to manual input devices. In multi-man training systems where fast access to much information in multi-formats is necessary, the selection of manual input controls with compatible displays is an important decision for training management. The alternatives available in the selection of controls include the following:

- Switch/indicator array (engraved legends)
- Digit keyset
- Alpha-numeric keyboard
- Joystick (cursor symbol positioner)
- Trackball (cursor symbol positioner)
- x-y multi-gain push buttons (cursor symbol positioners)

- light pen (or light gun)

Note: The 14A2 employs switch indicator arrays and digital keyboards.

4.6.5.2.2 Scenario Modification--(off-line). These are the pertinent controls for the efficient setup of the initial conditions for an exercise and for enroute modifications in an exercise.

4.6.5.2.3 Ancillary and Power Supply. These are the controls associated with the operation of the training device, e.g., power to instructor console, mission initiation, emergency stop, lamp test, etc.

4.6.5.2.4 Communications. These are standard controls, functional replicas of existing equipment for two-way communications with trainees; with remote instructors; and with other associated personnel.

4.6.6 Monitor and Control of Training (During the Training Exercise)

To achieve the training purpose and the training objectives, the characteristics of the instructional capability must be specified. It is desirable that 14A2 design provide the capability to exploit two major levels of team training in the mission (screen, SAU) contexts and controls and displays must be provided at the instructor console so that event positioning at prescribed times in the mission scenario can be set up. These two levels of training emphasis are outlined briefly below.

Level 1 emphasizes the operation of the ASW platform in which a series of "givens" are provided to the team for implementation, that is, the approach to the scene-of-action (direct, offset, intercept), search plans (area, intercept, lost contact), and attack plans and weapons systems are specified. This level of training provides a single thread through an exercise in that a number of decisions which have instructional expediency are made for the team (who customarily resolve these decisions themselves in the operational world). The emphasis at this level is on training in coordinated ASW procedures, i.e., can the team accomplish the activity sequences in ASW operations? The mission profile for a SAU operation can be diagramed as in Figure 52.

Level 2 does not employ "givens" but requires the team to select and implement a course of action required in an engagement. This is the realistic simulation of the complete engagement where a team performs as in the real world. This level emphasizes the tactical employment of the ASW platform since in complex operational situations several equally good

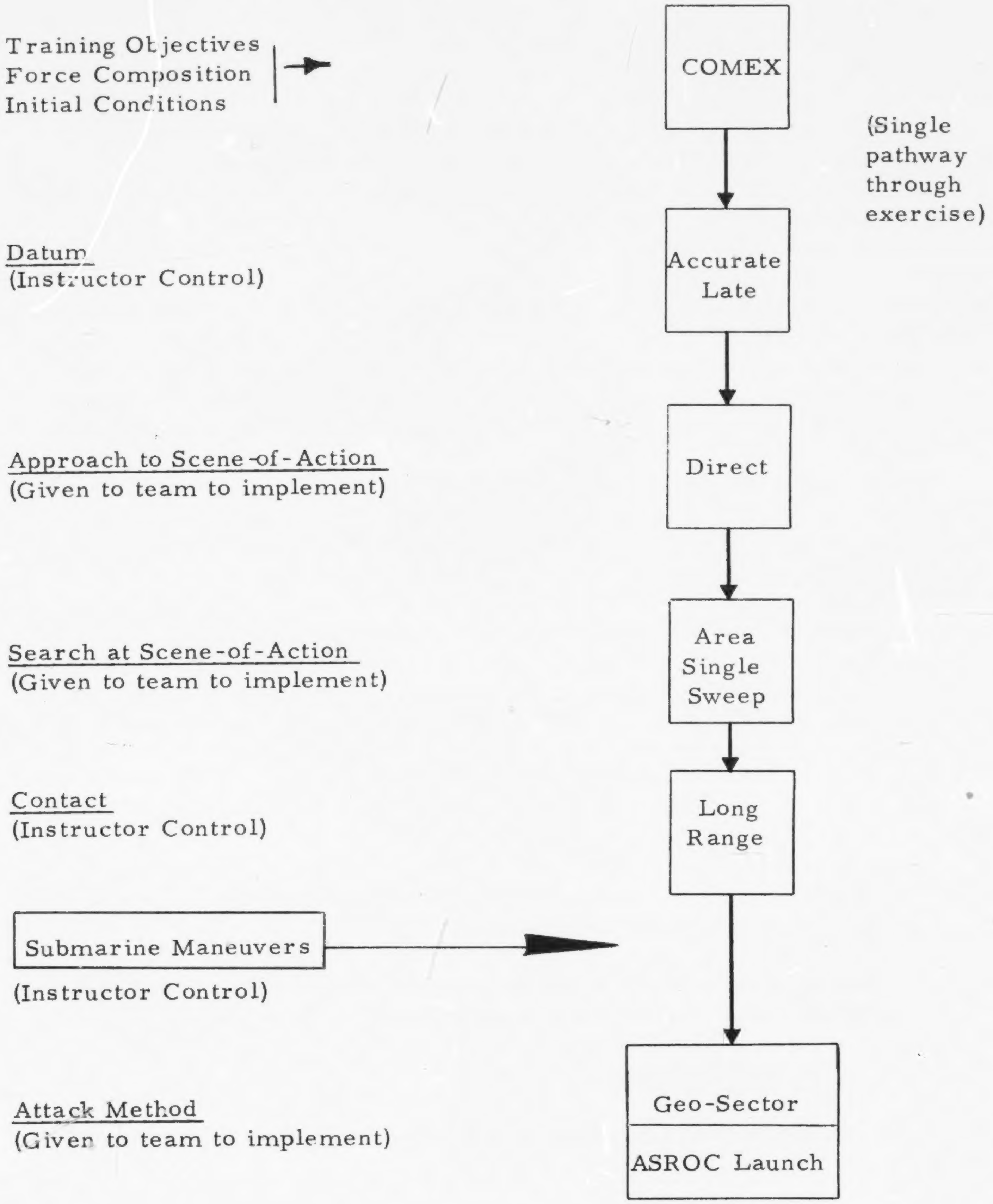

Training Objectives
Force Composition
Initial Conditions
COMEX
(Single pathway through exercise)
Datum
(Instructor Control)
Accurate Late
Approach to Scene-of-Action
(Given to team to implement)
Direct
Search at Scene-of-Action
(Given to team to implement)
Area Single Sweep
Contact
(Instructor Control)
Long Range
Submarine Maneuvers
(Instructor Control)
Attack Method
(Given to team to implement)
Geo-Sector
ASROC Launch

Figure 52. Level 1, SAU Mission Profile for Device 14A2

solutions to tactical problems exist so that differences between teams may become evident only in the way a team copes with the ASW situation.

What this recognizes is that there may be a number of equally good solutions to a problem, and that multiple pathways (decision points) exist for each exercise. For any exercise in Level 2, only the conditions at COMEX, the datum characteristics, the contact source and quality, and the submarine maneuvers are under instructor control. The remainder is developed and implemented by the team as prescribed by the mission requirements. Thus, equally good "multiple pathways" must often be considered for each exercise (one of which is the "single pathway" in the Level 1 counterpart). The problems to be solved are set in a "free play" context but with the structure and control necessary to insure standardized exercises in training. The mission profile for a SAU operation can be diagramed as in Figure 53.

The displays of necessary team performance information and the controls and the communications necessary to develop a training strategy for the team are specified. The options provided at the instructor console for structuring and controlling training include the following:

- Provide monitoring and control of performance via displays at the console. This information is used in judgments for continuing the mission as planned. Verbal communication capability with trainees is required throughout the training exercise.
- Provide demonstration capability for a team before the briefing is begun.
- Provide freeze capability of an exercise for demonstration, guidance or administrative hold.
- Provide for control of the pace of the training (e.g., variations in the maneuvering of the submarine)

4.6.7 Pre-Mission Requirements

The hardware requirements in pre-mission activities involve the following:

- System initialization confidence checks, power requirements, program insertion
- Setup of initial conditions for an exercise.

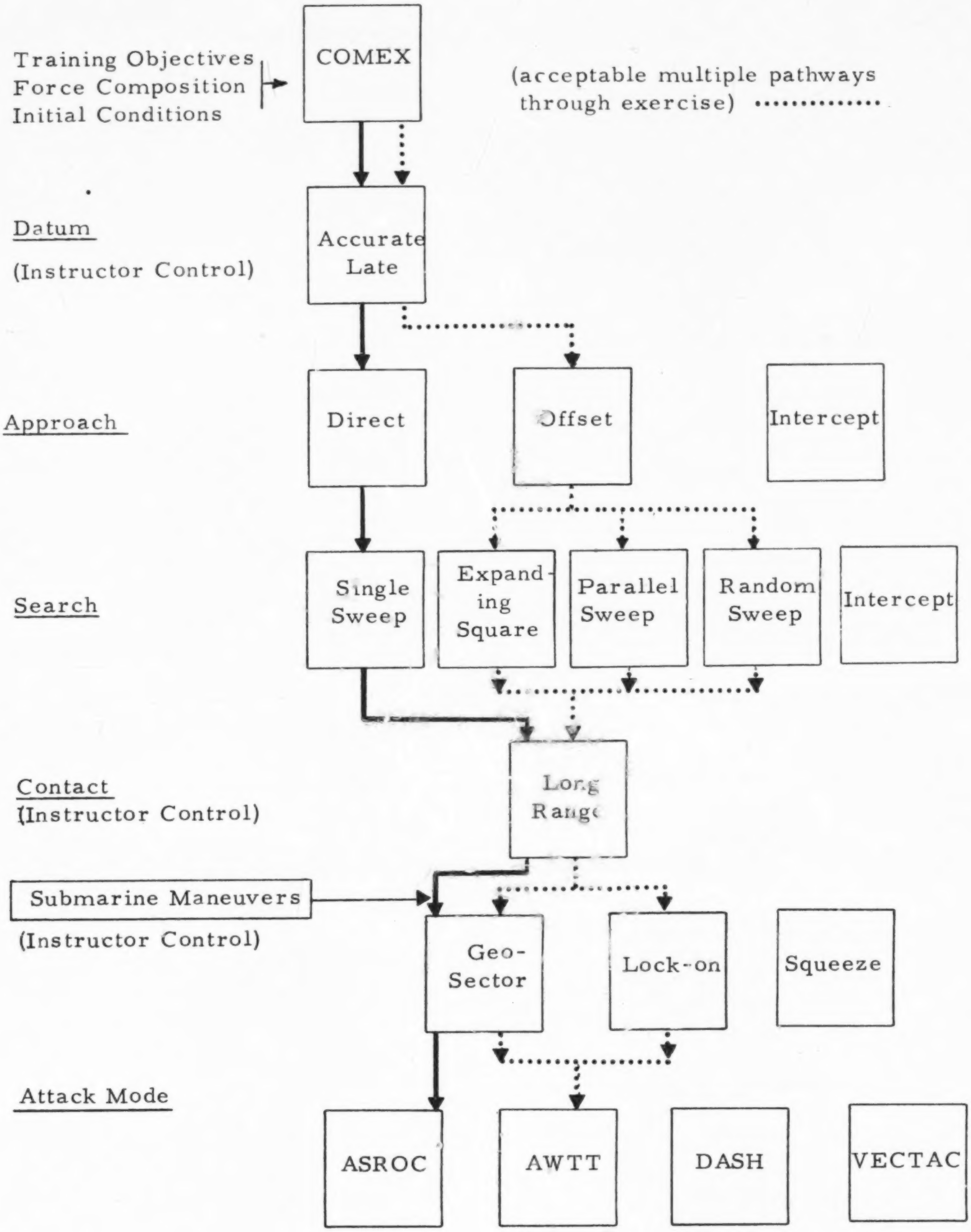

Training Objectives
Force Composition
Initial Conditions
COMEX
(acceptable multiple pathways through exercise)
Datum
(Instructor Control)
Accurate
Late
Approach
Direct
Offset
Intercept
Search
Single Sweep
Expanding Square
Parallel Sweep
Random Sweep
Intercept
Contact
(Instructor Control)
Long Range
Submarine Maneuvers
(Instructor Control)
Geo-Sector
Lock-on
Squeeze
Attack Mode
ASROC
AWTT
DASH
VECTAC

Figure 53. Level 2, SAU Mission Profile for Device 14A2

The manipulatables that are controllable in the setup of the initial conditions are:

- Own-ship
  - course
  - speed
  - position (XY)
  - equipment malfunction

- Support units
  - range
  - bearing
  - course
  - speed
  - altitude (aircraft)

- Target
  - position (including contact (xy) at prescribed time)
  - range
  - bearing
  - course
  - speed
  - depth
  - type submarine (via speed)
  - aspect
  - doppler
  - false target (decoy, i.e., multiple echoes)

- Environment
  - sea state
  - layer depth
  - wind

- Weapons
  - ASROC
  - DASH
  - AWTT
  - nuclear depth charge
  - a/c torpedoes
  - submarine torpedoes

4.6.8 Post-Mission Requirements

The hardware implications in instructor post-mission activities involve special equipment for the critique of team performance. Since no automated preprogramed scenarios are employed (i.e., no requirement for recycling vs. shutting down the system) and no hard copy printouts of team performance are required (i.e., for on-line critique information and for school record-keeping), the requirement considers only equipment for mission replay. What is needed is a visual display projection (UPG system) and audio recording (tape) for the reconstruction of a mission just completed.

4.6.9 Measurement Capability

Measurement is undertaken to enable the instructor staff to assess the progress and the outcomes of team training. Its purpose is to provide objective descriptions of team performance necessary for a meaningful critique of an exercise and to provide a data base for the school record-keeping function. The exercise critique provides feedback to the team on how well it performed the exercise. This feedback can only be effective if two conditions are met. First, the instructors must systematically observe and record team performance during an exercise. Second, they must have an objective basis for determining the adequacy of the performance observed.

The systematic observation and recording of team performance requires that a measurement system be available for the exercises conducted. This serves to standardize the observing of performance and thus is designed to assist the instructor in the conduct of the critique. Thus, measurement establishes a basis for providing the team knowledge of results of its performance, thereby serving a role in the learning process. Measurement also indicates how the team is progressing and is a basis for exercise selection (training strategy) by the instructor staff.

A well-developed measurement system (i.e., automated scoring and recording, hard copy printouts of team performance for critique and school record-keeping functions) is desired, since this could enhance training effectiveness by providing an array of objective and standardized indicants of performance. The advantage of this for developing a strategy for training individual teams, for refining the school curriculum and for maintaining quality control of training is obvious.

> Note: For the 14A2 device, the decision was made to provide a minimal scoring and recording of performance capability.

Three types of performance observation are employed in the 14A2 to determine how a team is progressing. These are as follows.

- The occurrence/non-occurrence of critical events to be accomplished in the exercise are recorded. These are provided in checklist format for each exercise and identify the key procedural activities (equipment operation and communications) to be performed in the subteam compartments. Also, a situational display (UPG replay capability) of the total mission and the critical events are recorded for the critique.

- Quantitative scores of time and accuracy in developing fire control solutions are obtained. Hardware provisions are made for the following display of information.

    - Fire control solution: team-determined target course and speed, range/bearing which can be compared with actual target range and bearing.

    - Digital readouts on weapons: how close the fired torpedo comes to the target; range/bearing, depth, course, speed and aspect information is provided. Water entry point (WEP) in relation to the target can be determined. Also, control and attack accuracy (e.g., MAD accuracy) is provided on the ASAC console.

    - Digital readouts of time of attack intervals: elapsed time from contact to first attack; from first to second attack; and from second to third attack is provided.

- Instructor judgments are relied upon for evaluating the more complex segments of team performance involving coordinated activities among team members. These are concerned with the team's ability to employ itself and its resources in the approach, search, and contact prosecution phases of destroyer ASW missions (e.g., sensor employment, weapons employment and vectoring or positioning of units under control by the team). In addition, team coordination is judged by the internal and external communications discipline and by the quality of the communications (content, anticipation of needs of other members, and lateness in conveying information).

An overall team score or grade is not provided for an exercise. The assessment purpose is to determine whether or not the team achieved the training objectives of the exercise. Since measurement focuses on team performance evaluation for use in the exercise critique, it is tailored to obtaining those performance indications that can realistically be obtained during the exercise for use immediately after exercise completion.

The training standards that apply to the 14A2 training are directly related to the three part measurement system just discussed (occurrence of critical events, time and accuracy of fire control solutions, judgments of performance).

4.6.10 Communications

The communications capabilities at the instructor station duplicate those required in the ASW environment. The following links have common usage among all subteam compartments.

- 21 MC, 27 MC, 29 MC, intercom.
- Sound powered telephones--1JS (ASW control), 21JS, 22JS (radar announcing circuit), 61JS (sonar announcing circuit), and JA, JC, 8JP, 5JV.
- RT nets--maximum of four to accommodate: PRITAC, SAUTAC, screen common, SAU CI, ASW common, ASW air control net.

Also, provisions are made at the instructor station for ASW contact alarm and ASW salvo alarm buzzer.

4.6.11 Overall Workplace and Layout Requirements

We will not emphasize the human engineering design and layout of the 14A2 instructor station complex except to indicate and comment on basic layout requirements. An ample supply of human engineering design standards and military specifications are in existence and are applicable to this device class. Design should conform to these specifications, as pertinent. Suffice it to say that the instructor station layout should be accomplished in modularized components consistent with primary and secondary use requirements and with established human engineering design practices.

We will, however, comment on a number of inadequacies in the instructor station layout that violate good design practices and in some instances hamper the instructional capability. The luxury of hindsight provides us with an assist in this task.

4.6.11.1 Physical Layout. A total of eleven consoles arranged in a straight line comprise the instructor station complex. The arrangement and identification of the consoles are shown in Figure 54. In essence, the physical arrangement is cumbersome; the consoles are aligned side-by-side over a considerable area and it is difficult for one instructor to use the controls and displays efficiently. The eleven consoles in the linear array cover 21 feet of space, each console is 46 inches high and 43 inches deep. There are, for example, three identical consoles (vehicle control). However, in the present setup, this number is required for complex multi-unit tactical problems.

The cumbersomeness of the layout is measured in a number of design inadequacies. Representative ones are outlined below to provide a flavor of the types of features that burden the instructor. (The good features of design are tacitly recognized in this section.) A number of control and display placement features are identified using as a referent the primary usage in relation to the master console.

- The fire control console should be positioned closer to the master console in terms of usage; the fire control and the vehicle data consoles should be together.
- Weapon presettings should be on the master console instead of on the Fire Control (computer display) console.
- The seascape console is positioned too remote from the master console and cannot be seen directly.
- Controls and displays for handling the assist ship and flying an aircraft are too far apart for multi-unit exercises.
- The event symbol for the projector display (environment console) is too remote from the master console since it must be activated for every piece of critical information added to the projection display. It would be more advantageously placed on the master console.
- Submarine control (vehicle control console) should be moved so that the operator cannot see the whole tactical environment as it develops (which is an advantage to him in positioning the submarine).
- At present, weapon readout requires multiple button depressions simultaneously. A single button activation would eliminate this cumbersome feature.

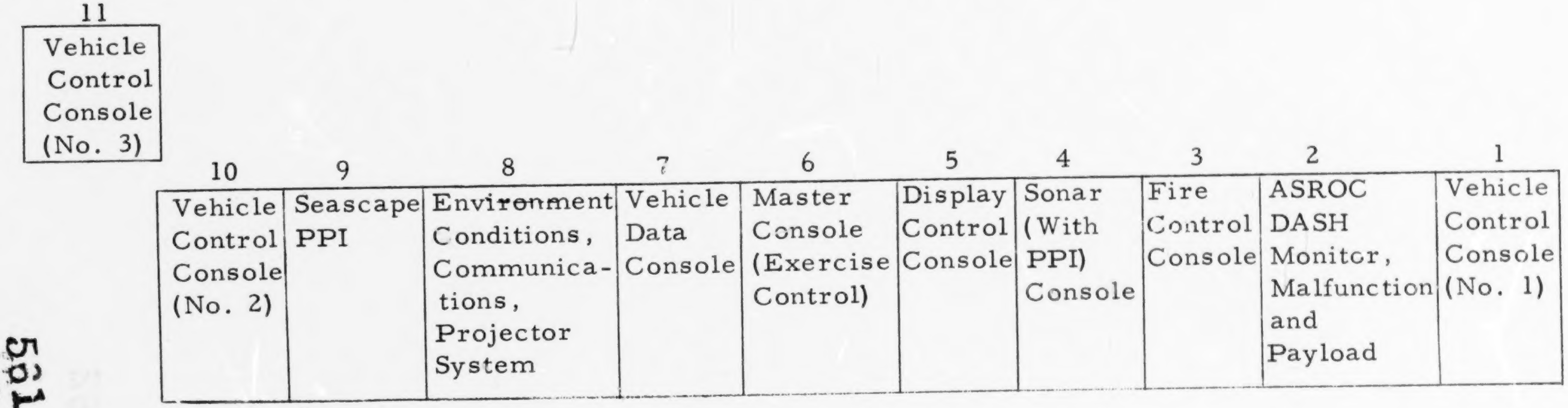
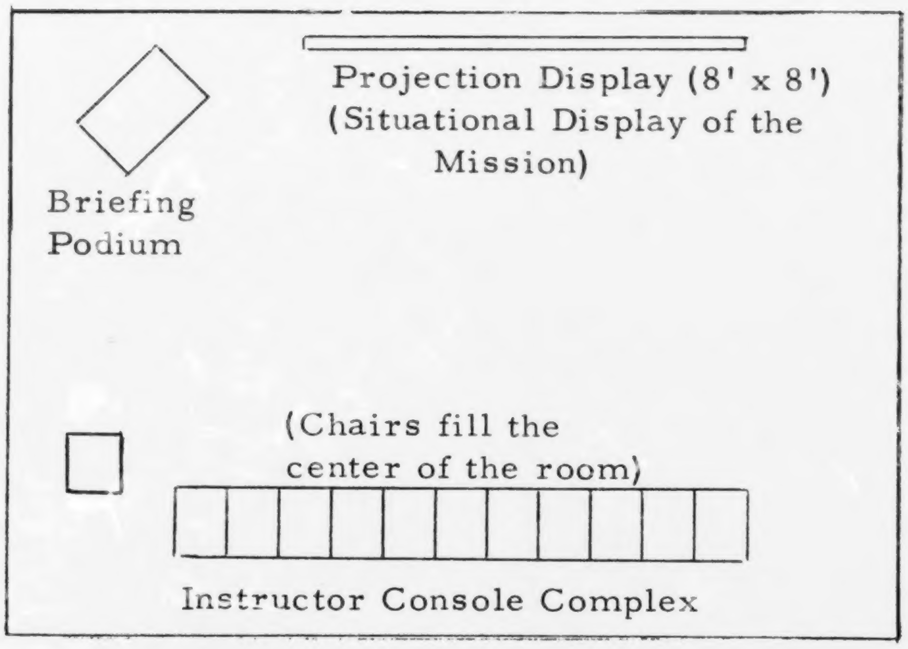

11
Vehicle Control Console (No. 3)
10
Vehicle Control Console (No. 2)
9
Seascape PPI
8
Environment Conditions, Communications, Projector System
7
Vehicle Data Console
6
Master Console (Exercise Control)
5
Display Control Console
4
Sonar (With PPI) Console
3
Fire Control Console
2
ASROC DASH Monitor, Malfunction and Payload
1
Vehicle Control Console (No. 1)

Figure 54 Arrangement of Instructor Station Consoles, Device 14A2-B.

4.6.11.2 Special Design Features. The instructor console complex is located in the problem control room as shown below.


Projection Display (8' x 8')
(Situational Display of the Mission)
Briefing Podium
(Chairs fill the center of the room)
Instructor Console Complex

A design requirement is that direct visual access be provided to the projection display throughout the running of a mission. In the design selected, console heights were set at 46 inches from the floor to enable instructors to see the projection display.

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13. ABSTRACT

This report presents guidelines for achieving human factors inputs to the design of synthetic training systems. It provides a method for design and organizes training concepts and data supportive to the human factors specialist in deriving the functional specifications for the design of any complex training device.

Three major sections are provided. The first of these presents an organized method for achieving human factors inputs to training system design.

Another section presents concepts and data applicable to the design of training devices. Seven content chapters are subsumed under this section. These are: (1)visual simulation, (2) platform motion simulation, (3) vehicle control requirements, (4) information processing requirements, (5) measurement system design, (6) adaptive training strategies, and (7) deliberate departure from realism in design. For each chapter concepts and data which provide human factors design support are articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Research issues of high priority for human factors design are recommended.

The final section provides a demonstration of the human factors design process for a complex training system. A reconstruction of the human factors specifications for Device 14A2, ASROC/ASW Early Attack Warning System Trainer, is presented. The required human factors inputs are systematically explored based on the method mentioned above. Viewing an "on-line" training device in retrospect provides the opportunity to examine the credibility of the method proposed in this report, particularly in relation to the design achieved. It also enables the reconstruction of the key human factors decision points including an examination of the possible design alternatives in terms of what effects these could have had on the instructional capability of the device.

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